

1998

Automatic Car Registration Plate Recognition Using the Hough Transform

Shokri Gendy
Edith Cowan University

Follow this and additional works at: <https://ro.ecu.edu.au/theses>



Part of the [Mechanical Engineering Commons](#)

Recommended Citation

Gendy, S. (1998). *Automatic Car Registration Plate Recognition Using the Hough Transform*.
<https://ro.ecu.edu.au/theses/1429>

This Thesis is posted at Research Online.
<https://ro.ecu.edu.au/theses/1429>

Edith Cowan University

Copyright Warning

You may print or download ONE copy of this document for the purpose of your own research or study.

The University does not authorize you to copy, communicate or otherwise make available electronically to any other person any copyright material contained on this site.

You are reminded of the following:

- Copyright owners are entitled to take legal action against persons who infringe their copyright.
- A reproduction of material that is protected by copyright may be a copyright infringement. Where the reproduction of such material is done without attribution of authorship, with false attribution of authorship or the authorship is treated in a derogatory manner, this may be a breach of the author's moral rights contained in Part IX of the Copyright Act 1968 (Cth).
- Courts have the power to impose a wide range of civil and criminal sanctions for infringement of copyright, infringement of moral rights and other offences under the Copyright Act 1968 (Cth). Higher penalties may apply, and higher damages may be awarded, for offences and infringements involving the conversion of material into digital or electronic form.

USE OF THESIS

The Use of Thesis statement is not included in this version of the thesis.

**AUTOMATIC CAR REGISTRATION PLATE
RECOGNITION
USING THE HOUGH TRANSFORM**

**By
Shokri Gendy**

**A Thesis Submitted in Fulfillment of the Requirements for
the Award of**

Master of Engineering Science

Principal Supervisor: Associate Professor Clifton Smith

Associate Supervisor: Dr Stefan Lachowicz

At the School of Engineering

Edith Cowan University

Western Australia

ABSTRACT

The development of automatic car registration plate recognition systems will provide greater efficiency for vehicle monitoring in automatic access control, and will avoid the need to equip vehicles with special RF tags for identification since all vehicles possess a unique registration plate. Thus this study is an attempt to introduce an automatic car registration plate recognition system based on identifying the plate characters by using the Hough transform. However, the proposed recognition system can be used in conjunction with a tag system for higher security access control. The automatic registration plate recognition could also have considerable potential in a wide range of applications especially in the identification of vehicle-based offences and with law enforcement.

Recent advances in computer vision technology and the falling price of the related devices has contributed in making it practical to build an automatic registration plate recognition systems. There have been a number of Optical Character Recognition (OCR) techniques, which have been used in the recognition of car registration plate characters. These systems include the character details matching process (Lotufo, *et al.* 1990), BAM (Bi-directional Associative Memories) neural network (Fahmy 1994) neural network (Tindall 1995) and cross correlation pattern matching character matching techniques (Comelli, *et al.* 1995). All of these systems recognized the characters by matching the full image of every character with a character's template database which requires considerable processing time and large memory for the database.

The purpose of this study is to explore the potential for using Hough transform (Hough 1962) in vehicle registration plate recognition. The OCR technique used in this project is unlike the other systems where the character recognition was based on matching the character's full image. However the OCR technique in this system used Hough transform to identify the characters, where the recognition of a character is based on matching its identification array to the database.

To validate the research, a car registration plate recognition system was developed to locate the registration plate from the full image of a vehicle and then extract the plate characters by using image processing techniques. A Hough transform algorithm was applied to every character within the registration plate image to produce an identification array for these characters, and the plate characters were recognized by matching their identification array to the database.

The system has been applied to a number of video recorded car images to recognize their registration plates. The rate of correctly recognized characters was 82.7% of the extracted characters, but improvement can be granted by using a faster digital camera and taking some precautions in the registration plate frames. However, the research indicated that the optical character recognition technique used in the study is an efficient and simple algorithm to identify characters, without requiring a relatively large processing memory.

DECLARATION

I certify that this thesis does not, to the best of my knowledge and belief,

- (i) incorporate without acknowledgment any material previously submitted for a degree or diploma in any institution of higher education;
- (ii) contain any material previously published or written by another person except where due reference is made in the text; or
- (iii) contain any defamatory material.

Signature:

Date: 17 - 8 - 1998

ACKNOWLEDGMENTS

I would like to acknowledge and express my sincere thanks to Associate Professor Clifton Smith for his encouragement, help, time and guidance during the preparation and writing this thesis.

I would like also to thank Dr. Stefan Lachowicz for his help and time in the experimental work

Thanks to my family, including my wife Moona and children Mina and Monica for their encouragement and supportive attitude, which enabled me to complete this study.

TABLE OF CONTENTS

ABSTRACT	i
DECLARATION	iii
ACKNOWLEDGMENTS	iv
TABLE OF CONTENTS	v
LIST OF FIGURES	ix
LIST OF TABLES	xi
CHAPTER 1: INTRODUCTION	1
1.1 Background to the study	1
1.2 The significance of the study	3
1.3 The aim of the study and research question for the thesis	3
1.4 Proposed approach for the development of the system	4
1.5 Organization of the thesis	5
CHAPTER 2: THEORY AND BACKGROUND	8
2.1 Car registration plate recognition techniques	8
2.1.1 Background of the study	8
2.1.2 Registration plate recognition using B.A.M. neural network.	9
2.1.3 Registration plate recognition by using cross correlation pattern matching	11
2.1.4 The study design	13

2.2 The Hough transform	14
2.2.1 The Hough transform theory	14
2.2.2 The Hough transform for the discrete lines	18
2.3 The Hough transform in car registration plate recognition	21
2.3.1 Image identification using Hough transform	21
2.3.2 Plate tilt detection by using Hough transform	22
2.4 Chapter conclusion	23
CHAPTER 3: LITERATURE REVIEW	24
3.1 Literature on image processing	24
3.1.1 Edge detection	24
3.1.2 Image segmentation	25
3.1.3 Image recognition	26
3.1.4 The morphological analysis	28
3.2 Literature on registration plate recognition	28
3.2.1 Registration plate recognition using B.A.M. neural network.	29
3.2.2 Registration plate recognition by using cross correlation pattern matching	29
3.2.3 Another application of neural network technique to automatic registration plate recognition.	31
3.3 Literature on registration plate area detection.	32
3.3.1 Detection using color image processing.	32
3.3.2 Locating the registration plate area using gray-scale morphology	33
3.4 The fast Hough transform	34

CHAPTER 4: THE STUDY	36
4.1 The feasibility study	36
4.1.1 Evaluating the Procedures of Plate Recognition	37
4.1.2 The hardware requirements	40
4.1.3 Choosing the software.	41
4.2 The pilot study	42
4.2.1 Preparing the database	42
4.2.2 Testing the System on Manually Extracted Plates	44
4.2.3 Evaluating the pilot results	46
4.3 The methodology	48
4.3.1 Character identification	48
4.3.2 Registration plate area detection	53
4.3.3 Normalizing the plate	57
4.3.4 Characters extraction and the preparation for the identification process.	59
4.3.5 The character identification database	65
4.3.6 Matching the character identification with the database	68
CHAPTER 5 RESULTS AND INTERPRETATION	70
5.1 The results	70
5.1.1 Plate area extraction	74
5.1.2 Character area and characters extraction	76
5.1.3 Registration plate recognition	77
5.1.4 The execution time	81
5.2 Analyses of the results	82
5.2.1 Analyses of the extraction process	82
5.2.2 Analyses of character recognition process	82
5.2.3 Evaluation of execution time	83
5.3 Interpretation and outcomes	84
5.3.1 Results interpretation	84
5.3.2 Outcomes of the Hough transform	85

CHAPTER 6 CONCLUSION	87
6.1 Overview of the study	87
6.2 Limitation of the implementation	90
6.3 Outcome and conclusion	91
6.4 Implementation of the study and recommendation for further research	92
REFERENCES	94
APPENDIX A: Published Paper Presented the Study	98
APPENDIX B: Algorithm Subroutines	110

LIST OF FIGURES

Figure 2.1:	Bi-directional associative memories (B A M)	10
Figure 2.2:	A line in the xy plan	15
Figure 2.3:	Parameter space and line bundle associated with the solution	16
Figure 2.4:	Parameter space cells	17
Figure 2.5:	Normal representation of a line	17
Figure 2.6:	digital lines	19
Figure 3.1:	Sobel edge detector masks	25
Figure 4.1:	Vertical colour concentration of a plate character	38
Figure 4.2:	Schematic diagram showing the hardware organization	40
Figure 4.3:	Extracted characters area from the plate	45
Figure 4.4:	Horizontal edges of a character	45
Figure 4.5:	Vertical edges of a character	46
Figure 4.6:	The quadrants of the parameter space	52
Figure 4.7:	An extracted plate area	56
Figure 4.8:	Horizontal edge of a tilted registration plate	57
Figure 4.9:	Tilt angle distribution for a registration plate	58
Figure 4.10:	The binary image of a registration plate	60
Figure 4.11:	A typical Australian car registration plate	61
Figure 4.12:	Horizontal colour concentration of plate characters	61
Figure 4.13:	Registration plate after separating the top and bottom parts	62
Figure 4.14:	Vertical colour concentration of plate characters	62

Figure 4.15:	Vertical colour concentration of plate characters after the vertical separation	63
Figure 4.16:	Registration plate after the vertical and horizontal separation	63
Figure 4.17:	Vertical colour concentration for the extracted character area	64
Figure 5.1:	The distribution chart of the extraction modes	75
Figure 5.2:	The distribution of the correctly recognized characters per plate	78
Figure 5.3:	A group of lines in the positive image space quadrant	85
Figure 5.4:	A group of vertical lines in the rotated axis image space	86

LIST OF TABLES

Table 4.1:	Hough transform identification of registration plate characters	43
Table 4.2:	Extended character identification database	66
Table 5.1:	The results of applying the imaging system to the test plates	72
Table 5.2:	Plate extraction mode result.	75
Table 5.3:	Results and percentage of the correctly extracted characters	76
Table 5.4:	The correctly recognized characters per plate	77
Table 5.5:	The correctly recognized characters compared to the correctly extracted characters and total number of character in the tested plates	78
Table 5.6:	Recognition statistics for the mistaken characters	79
Table 5.7:	The execution time for extraction and recognition process	81

CHAPTER 1

INTRODUCTION

Law enforcement agencies have traditionally identified vehicles by their features such as colour, shape and model, or alternatively by the registration plate which is a unique identification for each car. In order to automate the recognition of a vehicle, imaging systems have been developed to perform this task. As a result, many studies on automatic plate recognition have been reported over the last decade, and the ongoing development of the automatic car registration plate recognition system will have an important role in future security, traffic control and vehicle identification systems.

1.1 Background to the Study

The automatic identification of vehicles has been in considerable demand especially with the increase in the vehicle-related offences. Vehicle identification has an important role in security zone access control and automatic toll road collection together with law enforcement surveillance, and the capacity to identify vehicles will allow future highway control.

Many identification systems have been introduced since the end of the last decade and early 1990's, such as the work of Lotufo, Moran and Johnson (1990) where they used a boundary following technique to extract the registration plate from the car image and to separate the characters from the plate area. The technique utilized a detailed matching process to recognize the characters. Fahmy (1994) employed a BAM neural network to recognize the registration plate characters. To extract the registration plate area Lee, Kim and Kim (1994) applied a colour image processing technique, while Poon, Gladioli, Man and Shoeing (1995) used a gray scale morphological process. Comelli, Ferragine, Granieri, and Sabil (1995) applied a technique that can search the image and detect the area of maximum contrast to extract the registration plate and calculated the cross correlation between the plate characters images and the database templates to recognize the characters. Tindall (1995) extracted the plate using a system to search for plate-like

structure and then a neural network applied to recognize the extracted characters.

These studies indicate the possibility of automatic registration plate recognition for the plates of different nationalities including British, Korean and Italian, but none have been applied to Australian registration plates. Although these studies used different techniques for the character recognition, all were to match the character image to the database.

The automatic car registration plate recognition procedures described in the previous studies were performed by the following steps:

- (a) Extraction of the registration plate from the image of the vehicle was performed in a number of techniques including Lotufo, *et al.* (1990) where they applied a boundary following technique, Lee, *et al.* (1994) applied a colour image processing technique, Poon, *et al.* (1995) used a gray scale morphological process, Comelli, *et al.* (1995) utilized a technique that can search the image and detect the area of maximum contrast to extract the registration plate and Tindall (1995) applied an algorithm search for the plate-like structure in the car image.
- (b) The normalization of the registration plate area where this process was applied to the tilted plates by firstly measuring the tilt angle of the registration plate and then rotating the registration plate image in the opposite direction. Comelli, *et al.* (1995) used the minimum spreading of the plate character's local colour minima and maxima to measure the plate tilt angle.
- (c) The character feature extraction process was described by Lotufo, *et al.* (1990) who used a boundary following technique to extract the characters, while Poon, *et al.* (1995) and Comelli, *et al.* (1995) depended upon the regularity of the registration plate and the system to estimate the location of any character within the plate.
- (d) The databases for the techniques applied by Lotufo, *et al.* (1990), Fahmy (1994), Lee, *et al.* (1994), Comelli, *et al.* (1995) and Tindall (1995) were in the form of templates for the characters used in the registration plate.
- (e) The work of Lotufo, *et al.* (1990), Fahmy (1994), Lee, *et al.* (1994), Comelli, *et al.* (1995) and Tindall (1995) in car registration plate recognition showed that they have dealt with plate character in different ways of recognition. The techniques applied for plate characters recognition were character details matching process (Lotufo, *et al.*, 1990),

neural network for matching character image (Fahmy, 1994, Lee, *et al.*, 1994 and Tindall, 1995) and cross correlation pattern matching (Comelli, *et al.*, 1995). Even these methods were different in the matching technique, but all techniques were matching character images to the database.

1.2 The Significance of the Study

The purpose of this study is to explore the efficiency of a new technique of Optical Character Recognition (OCR) for car registration plate recognition by the application of the Hough transform for the registration plate characters identification. The process will produce an identification array for every character by using the Hough transform, then this identification array will be used in this project to recognize the plate characters.

In the other systems for car registration plate recognition, the character recognition process was performed by comparing the character image to a database which includes the expected character templates. Unlike the other techniques, the methodology of this study for recognizing the registration plate characters was performed by comparing the character identification array to the expected character's identification in the database. Thus because the number of parameters in the character identification array produced by the Hough transform and used in this study is much less than the number of pixels of a character image, it is expected that the database memory will be reduced.

This is the first study applied to examining the possibility of using an automatic car registration plate identification system on Australian plates. There are also some recommendations for the registration plate construction to make it more suitable for automatic car registration plate recognition.

1.3 The Aim and Research Questions for the Study

The aim of this study is to investigate the possibility of a new technique of optical character recognition. This technique will be used to recognize the registration plate character by comparing its identification to the expected character's identifications. Also to examine the potential of a new application for Hough transform in image recognition, by applying the Hough transform to produce identification arrays for characters images.

This study addressed the following major questions:

- 1 Can the plate characters be recognized by comparing a character identification profile to an identification database?
- 2 Can the Hough transform technique successfully be applied to identify a character and how successful can it recognize the registration plates?
- 3 Is the Hough transform a reliable tool to produce identification of a character?
- 4 Is the Hough transform technique applicable for different sizes of characters?
- 5 Is the Hough transform technique applicable for registration plates with different tilt angles?
- 6 What is the structure and the configuration of car registration plate recognition system that can be used for the Hough transform technique for registration plate character identification and recognition and what is the efficiency of this system?
- 7 Can an automatic registration plate recognition system be used on the Australian registration plate?

1.4. Proposed Approach for the Development of the System

This study will examine the application of the Hough transform Optical Character Recognition (OCR) technique for vehicle plate recognition. The proposed system will be a combination of a sequence of procedures to extract the characters from the car image and then recognize them. The project will be conducted to recognize one form of the Western Australian registration plate with a yellow back ground. The procedures will be developed to include the following steps:

Registration plate area detection: As it is not possible to extract the character from the vehicle image, then this image should be segmented to extract the area that has the registration plate features.

Normalizing the plate: It is expected that the character identification will change with tilting and with varying the sizes of the plate. Therefore, it is important to normalize the plate before segmentation and identification.

Characters extraction: This process will be developed to extract the characters from the plate image for identification and recognition.

Character identification: In this step the extracted character will be identified by using the Hough transform technique. The character identification will be in the form of an array. The parameters of the identification array are expected to be much less than the number of pixels within the character image.

Database : A database which will be constructed, will become the reference to match an unknown character identification with one of the profiles within the database. Therefore the database should include identification profiles for all expected characters that the registration plates could contain.

Character recognition: In this step, the extracted character will be recognized by matching the unknown character identification array to the identifications of the database. The highest match will be the solution.

1.5 Organization of the Thesis

This thesis will present the background relating to this project as well as the full description for the project methodology. It will also review the results of the experimental tests for the project application and the analyses of the outcomes and results. Finally, the thesis will provide a conclusion about the project, which will include evaluation of the tests results and the outcomes of the project implementation.

Chapter One provides a discussion of the background, significance, aim and addressed questions of the study. The chapter also includes a brief discussion about the proposed car registration plate recognition system by using Hough transform and the organization of the thesis.

Chapter Two describes the theoretical background and the mathematical approach for the previous studies in car registration plate recognition. Also this chapter includes a review for the Hough transform mathematical approach and the application in car registration plate character's identification and registration plate tilt angle detection.

Chapter Three reviews the literature of the image processing techniques related to the project and includes such techniques as edge detection, image segmentation, image recognition and morphological analysis. Also this chapter reviews other research in car registration plate recognition and discusses the techniques used for character recognition and plate area location. Finally, a review of the latest research in the Fast Hough transform applied to overcome the problems that limit the application of this technique will be presented.

Chapter Four discusses the study, commencing with the feasibility study where the theoretical approach of recognition system used in this project was constructed and software and hardware were chosen. A description of the pilot study will be conducted in this chapter which investigates the possibility of applying the theoretical approach by using a limited experiment to test the registration plate recognition system. Also this chapter includes a description and discussion for the final format of the project methodology. The project methodology in this chapter will contain a description for every stage of the project including character identification, registration plate area detection, normalization of the plate, character extraction, database setup and matching the character identification to the database.

The experiment used to test the efficiency of the project system will be presented in Chapter Five. Also this chapter will include the results of applying every major stage of the experiment including the registration plate extraction, character extraction, and character recognition. An analysis of results and outcomes will be presented.

Chapter Six is the conclusion of the investigation with an overview of the study in general, followed by a discussion of the results of the experimental test and the outcomes from the research. Also this chapter will discuss the limitations of this study, followed by the conclusions about the project outcomes. Finally the chapter will discuss the implementation of the project technique and recommendations for the future research based on the processing techniques used in this study.

Two appendices are included at the end of the thesis. Appendix A contains the paper for the theoretical approach of this thesis, this paper was presented by Shoki Gendy, Clifton Smith and Stefan Lachowicz at the 31st annual International Carnahan Conference on Security Technology on October 1997. Appendix B contains a set of Matlab routines that forms the project algorithms.

CHAPTER 2

THEORY AND BACKGROUND

Automatic car registration plate recognition is considered one of the future law enforcement and access control tools that will replace traditional human monitoring and the use of radio frequency (RF) tags with greater job efficiency and less cost. Thus the automatic identification of vehicles has been in considerable demand worldwide especially with the increase in vehicle based offences. Automatic car registration plate recognition has an important role in security zone access control and automatic toll road collection. A number of systems have been introduced since the end of the last decade and early 90's, with a range of automatic car recognition techniques being used.

2.1 Car Registration Plate Recognition Techniques

There were many techniques used to achieve the plate recognition (Lotfo, Moran and Johnson, 1990; Fahmy, 1994; Lee and Kim, 1994 and Comelli, Ferragine, Granieri, and Sabil, 1995). These studies indicate the possibility of automatic registration plate recognition for plates of different nationalities (for example British, Korean, Italian, etc.) but none were applied specifically to Australian registration plates.

2.1.1 Background of the Study

The automatic registration plate recognition procedures in general are performed in the following steps:

- 1. Location of the registration plate:** When the vehicle is in range of the video camera, the vehicle triggers an inductive loop detector so that the camera captures an image of the front of the vehicle. The digital image will be stored in the memory ready for image processing. A segmenting algorithm on the full image will be used for segmenting the car image, and the segmented part that matches the registration plate features will be extracted for the optical character recognition.

2. **Normalizing of the registration plate area:** When the registration plate has been located, it could have a tilted orientation and/or not be of the standard size. This could prevent the features of the plate and its characters from matching the expected features. Thus it is most important to have the extracted plate normalized. This will be achieved when the system measures the tilt slope and the heights of the plate or the characters and, with an appropriate technique, apply a correction to normalize the image.
3. **Character feature extraction :** Another segmentation is required to separate each character in the registration plate image. This is also achieved by segmentation being applied to the normalized registration plate area in order to segment the characters from the plate background.
4. **Characters identification:** The identification of characters is only necessary for the systems that use an identification matching technique for image recognition. During this stage, the system produces a unique identification for every character used in the registration plate.
5. **Preparing the database:** The database consists of the registration plate character templates or identifications, where these templates or identifications are produced from actual registration plates.
6. **Character recognition:** A full image feature or an identification profile of the extracted character will be compared to the database for matching according to the best correlation factors.

The registration plate recognition process is a crucial stage for the identification of the characters by a matching technique. The following sections are a review of the main methods used for car registration plate recognition.

2.1.2 Registration Plate Recognition Using B.A.M. Neural Network

The Bi-directional associative memory (B.A.M.) is a neural network-based system used by Fahmy (1994) for the character recognition, and it is based on two layer feed back neural network as shown in the Figure 2.1 to encode patterns of the pair (A_i, B_j) . The encoding or learning in B.A.M. is carried out by modifying the weights between the neurons.

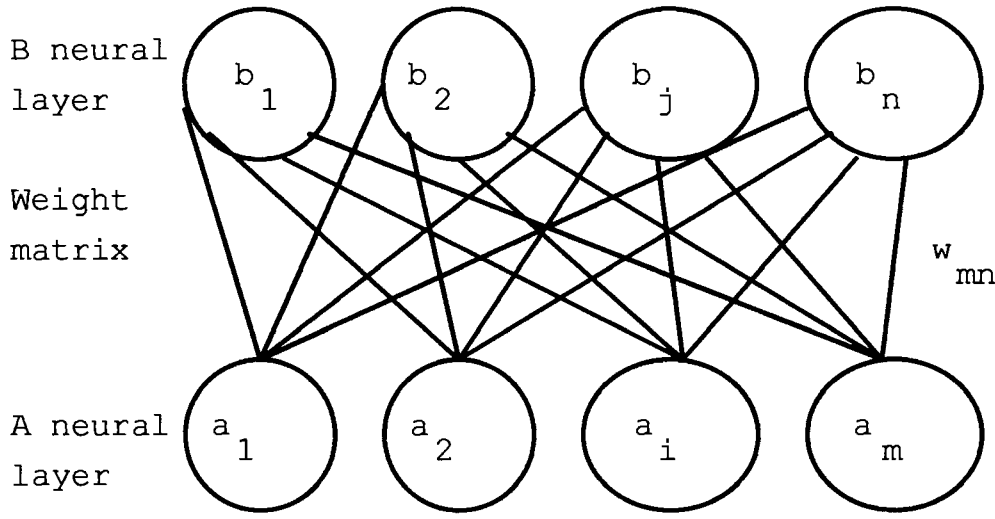


Figure 2.1. Bi-directional associative memories (B. A. M.)

The two neuron layers are totally connected to each other but are not connected to the neurons within the same field. Every neuron a_i is connected to each neuron b_j by "synapses", where these synapses form the weight matrix and the connection pattern between the neurons is the weight of connection. The Figure 2.1 shows that the network has two fields A , B , where field A of m neurons is:

$$F_A = \{a_1, a_2, a_3, \dots, a_m\}$$

and field B of n neurons is:

$$F_B = \{b_1, b_2, b_3, \dots, b_n\}$$

There are m neurons in F_A and n neurons in F_B , where every neuron is a simple nonlinear function that transforms the sum of the weighted input signal to an output signal. The simplest form of an output is the binary 1 or 0. The neurons turn on or off according to the input and the value of the threshold. For example, when a threshold equals 0, if the input to the neuron was positive then the output will be 1; and the same with the negative input, as it outputs 0 with the zero input, then the output will remain unchanged.

The neurons of the two arrays of field A and field B are in $-1, 1$. Then the B.A.M. would learn the association (A_i, B_i) by summing the correlation matrices, so that this association can be stored and recalled.

The weight between the two fields F_A and F_B , which includes the connection information, is contained by $m \times n$ matrix M . A stable B.A.M. is produced by different matrices M , where the network encodes a particular set of associations $\{(A_1, B_1), \dots, (A_p, B_p)\}$ by summing the dipole correlation matrices. In the learning process the binary pair (A_i, B_i) will be replaced by dipolar pair (X_i, Y_i) , where they are binary matrices using -1 's instead of 0 's. Every dipolar pair (X_i, Y_i) is converted to a bipolar correlation matrix (X_i^T, Y_i) (where X_i^T is the matrix transpose of matrix X_i). By adding the correlation matrices, then the mapping matrix can be obtained:

$$M = X_1^T Y_1 + X_2^T Y_2 + \dots + X_p^T Y_p$$

After the B.A.M. has been trained with a number of pattern pairs (A_i, B_i) , it produces the mapping matrix M . This matrix is able to recall B_i every time that A_i presents, or recall A_i when B_i presents. Also B_i will be recalled whenever something close to A_i is presented. With this operation Fahmy (1994) used the B.A.M. in the recognition of the characters within the registration plate.

2.1.3 Registration Plate Recognition by Using Cross Correlation Pattern Matching

The registration plate recognition process using cross correlation pattern matching was proposed by Comelli, Granieri and Stabile (1995). In this system the database was a group of prototypes for all letters and digits in a template in a reasonable gray level and in a standard size.

Registration plate normalization: Because of the needs of the selected recognition technique, it is important to have the characters at a constant size and without any tilt. Comelli, *et al.* (1995) achieved these conditions by the plate normalizing process which is performed in two steps:

- a. Estimating the character size and evaluating the registration plate tilt.
- b. Normalizing the plate according to this information.

The method used to estimate the tilt angle and character height is performed by scanning the character area in the registration plate and detecting some features of the plate. These features are called local minima points and local maxima points for the input image $f(x, y)$, where the local minima points satisfy the following condition:

$$\begin{aligned} f(x-2, y) &> f(x-1, y) > f(x, y) \\ f(x+2, y) &> f(x+1, y) > f(x, y) \end{aligned}$$

and local maxima points satisfy the following conditions

$$\begin{aligned} f(x-2, y) &< f(x-1, y) < f(x, y) \\ f(x+2, y) &< f(x+1, y) < f(x, y) \end{aligned}$$

These feature points which were extracted along the rows of the image are normally located at the character body and between the characters. The tilt angle can be determine by tilting the registration plate around its centre using suitable tilt angles between $(-\alpha_m + \alpha_m)$ and then measuring the spreading of the characters features (local minima and local maxima) for every tilt position. From the feature spreading histogram with different tilt angles α , the minimum spreading corresponds to the tilt angle α_1 . The character height is defined by measuring the orthogonal projections of the image features at minimum spread.

The row segmented image for the registration plate area is normalized by reassembling in two steps:

Firstly by rotating the image an angle α according to the definition:

$$\begin{aligned} x' &= x \cos(\alpha_1) - y \sin(\alpha_1) \\ y' &= x \sin(\alpha_1) + y \cos(\alpha_1) \end{aligned}$$

where x', y' are the new shifted positions of the x, y pixel.

After rotating the plate image to the normal, a second algorithm is used to adjust the plate size. The transformation is as:

$$\begin{aligned} x' &= kx \\ y' &= ky \end{aligned}$$

where k is the ratio between the desired plate height and the existing image height measured by the orthogonal projections of the image features at minimum spread, to fit it in a 20 x 230 pixels plate image.

Characters recognition: The standard sized character in the gray level image will be matched to all templates to measure the similarity. Comelli, *et al.* (1995) used the cross correlation technique to measure the similarity between the sub-image (f) where the character is expected, and the generic template (g), so that the result will be cross correlation value C_{fg}

$$C_{fg} = \frac{\sum \sum (f - f')(g - g')}{(\sum \sum (f - f')^2)(\sum \sum (g - g')^2)^{1/2}}$$

where f' , g' are the average gray level of both the generic template and the sub-image. By cross correlation of the sub-image to all generic templates, it will result in a number of cross correlation values. The generic template that gives the maximum cross correlation is the solution.

This system was applied to recognize the Italian registration plate by. Comelli, *et al.* (1995) and the result was 91% correct recognition.

2.1.4 The Study Design

The techniques of plate character recognition reviewed in Section 2.1 compared the full image of the unknown plate character to a set of known characters and the character that has the highest match will be the solution. This means that the comparison will be for every pixel within the entire character image; for example, a character image of the size 30 x 20 pixels the requires matching for 600 parameters which describes the character, and the matching process should be done for all available characters in the data base.

The analysis of the previous work shows that none of them covered the following areas:

- Studying a system that identifies the characters with a few parameters and then compares the unknown identification with a known group of characters, instead of using the full details.
- Examining the possibility of using the automatic car registration plate recognition system on the Australian plates

Therefore this study is an attempt to explore the efficiency of a new technique of character recognition by optical character recognition (OCR) for car registration plate recognition. Unlike the other systems where the full image is compared to a full images database, this system recognizes the character by comparing its identification or label to a characters identification database. Because character identification requires less information, the recognition will be faster and the database memory will be smaller. Also, it is the first study that examines the possibility of using the automatic car registration plate identification system on the Australian plates.

2.2 The Hough Transform

As it was mentioned in Section 1.3, it is required to construct a system for plate character recognition based on character identification, it was required to find a method that can give identification for these characters. The review of the image processing techniques showed that the Hough transform can be the most suitable method for identifying the plate characters, as the plate characters are composed of connected edge lines and the Hough transform is able to analyze the lines features. This Section is a review of the Hough transform in general, with the theoretical approach used in this project. This Section will also discuss the basis of the Hough transform for a digital image.

2.2.1 The Hough Transform Theory

The Hough transform was proposed by Hough (1962), where the Hough transform performs a structural relationship between pixels in an image. Consider a point (x', y') on a line with equation:

$$y = mx + c,$$

where m is the line slope and c is its intercept. For a point (x', y') in the xy -plane of the image space (Figure 2.2), there are an infinite numbers of lines that can pass through this point with different values of m 's and c 's.

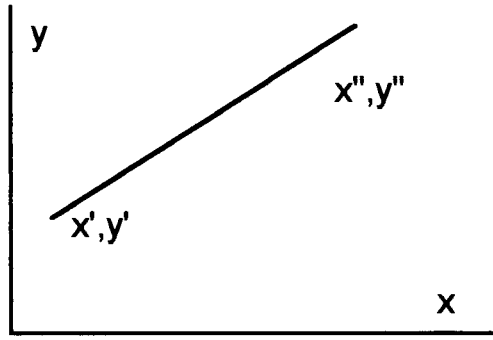


Figure 2.2. A line in the xy plan

Considering (x', y') is a fixed point in the image space, then the lines passing through this point should have variable parameters m, c where

$$c = -mx' + y'.$$

This is an equation for a straight line in parameter space (c, m plane). Similarly, for another point (x'', y'') in the image space can be presented as a line in parameter space through the equation $c = -mx'' + y''$. The intersection between the two lines in parameter space at the point (m', c') presents an image space including points (x', y') and (x'', y'') , with m' slope and c' intersection parameters.

When transferring every pixel of a line in the image space into lines in the parameter space (Figure 2.3), more lines intersect at the same point presenting a number of points along a line in the image space which is proportional to the length of this line.

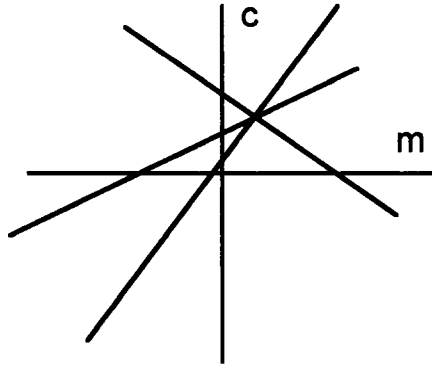


Figure 2.3: Parameter space and line bundle associated with the solution

For computing the number of lines passing through every solution point of parameter space, a parameter space should be constructed in the following shape:

- An appropriate diminution for the parameters space by choosing $(c_{max}, c_{min.})$ and $(m_{max}, m_{min.})$ which gives the range of the intercept and slopes values.
- Dividing the parameter space into four main quadrants centered by the zero slope column and zero intercept row.
- The quadrants subdivided into smaller accumulated cells having the unit size of the parameters **c** and **m**.

In Figure 2.4 the cell at coordinates (i, j) will have the value $A(i, j)$, which were initially zero. After the transformation of the full image, if the value of a cell $A(i, j)$ is greater than 1 then a solution is achieved with the number in this cell being equal to number of points passing by the image space line, and the location i, j presents the parameters of this line.

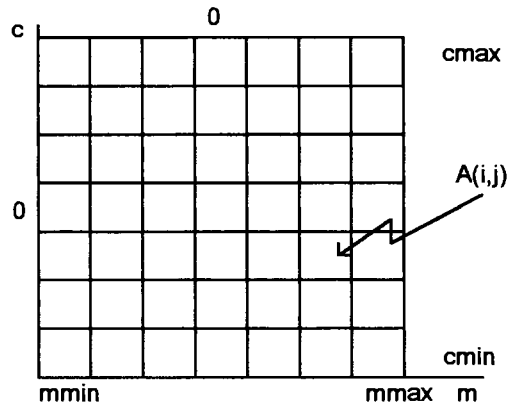


Figure 2.4: Parameter space cells

Also in the Cartesian coordinate, the Hough Transform can be applied in the normal representation of a line. Consider a line xy in Figure. 2.5 that has the equation:

$$\rho = x \cos \theta + y \sin \theta$$

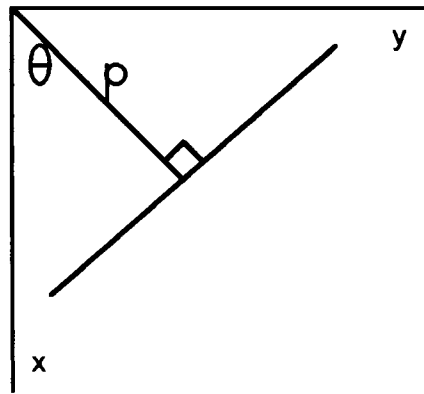


Figure 2.5: Normal representation of a line

This can be transformed in another parameter space ρ, θ plane, where every point in the image space will appear as a sinusoidal curve in the parameter space. When some curves intersect at a point, then this point will be the solution that gives the parameters ρ, θ and the number of intersected curves presents the image line length.

The Hough Transform is a very efficient tool in image identification and image recognition, but it had some difficulties in application:

1. Using the equation $y = mx + c$ does not function for vertical lines where the slope reaches infinity, and the solution point of those lines will be outside the limit of the parameter space. This limits the use of the Hough Transform only to transform the normal presentation of a line where the equation ($\rho = x \cos \theta + y \sin \theta$) can be used.
2. In the normal presentation transform, plotting every point in the image space as a sinusoidal curve in the parameter space (ρ, θ), plotting the curve point by point for every division of (θ) needs a large memory and a long execution time.

2.2.2 The Hough Transform For The Discrete Lines

Section 2.2.1 reviewed the transformation of a line in the Euclidean plan that has zero width pixels, while the processing of an image with a digital plan has the following features:

- The digital image is composed of pixels that have a certain width.
- The image has dimensions.
- Lines within this image are in a digital form where there is a limit to the number of slopes that the line could have.

The continuous straight line with a slope (m) and intercept (c), is given by the equation:

$$y = mx + c .$$

The possible representation of a similar digital line $D(m,c)$ with its slope in the limit $-1 \leq m \leq 1$, is in the form

$$y = \lfloor \; m \, x + c + 1/2 \; \rfloor \tag{2.1}$$

(NB.: The notation $\lfloor \; \rfloor$ is to show that the result was rounded down)

The digital line segment $D(m,c)$ is formed by pixels joining the grid point $(0,c)$ and $(X-1, c+h)$, where X is the number of pixels in the x direction and h is the point of the line intersection with the right side of the image.

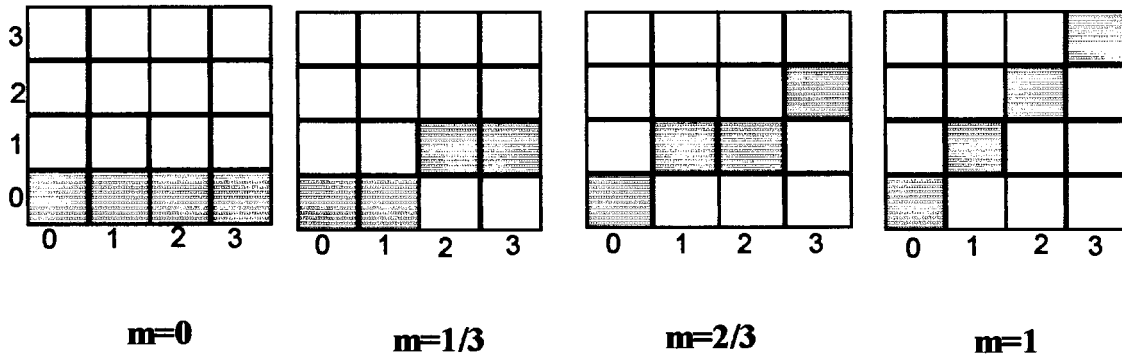


Figure 2.6. Digital lines.

The Figure 2.6 shows digital lines plotted according to the equation (2.1), where these lines have slopes $(m) = 0, 1/3, 2/3$ and 1 , the intercept of these lines (c) is equal zero and the end intersection $(h) = 0, 1, 2, 3$.

Each element of the Hough transform in the parameter space cell addressed by m and c of the digital line $D(m,c)$ is the sum of all the points in image domain (P) located on each discrete line D :

$$H(m,c) = \sum_{0 \leq x < N} P(x, \lfloor mx+c+1/2 \rfloor) \quad (2.2)$$

The construction of the parameter space for an image of the size Y height and X width, is firstly required to chose the number of slopes that can implement a proper solution for the transform. For (M) number of slopes of the image space lines, the size for m direction of the parameter space cells should be $(2M+1)$, where it should be doubled to cover positive and negative slopes and include an extra column for the zero slope.

An example of this transform, let P be an image of two lines:

$$\begin{aligned} y &= -x + 3 \\ y &= x/3 + 1 \end{aligned} \quad \text{and} \quad (3)$$

The digital implementation will be

$$P = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Using equation (2.2) to transform every line pixel of the parameter space, will result in the H parameter space:

$$H = \begin{bmatrix} (4) & 3 & 3 & 1 & 1 & 1 & 1 \\ 1 & 3 & 2 & 3 & 1 & 0 & 0 \\ 1 & 3 & 2 & 3 & 1 & 0 & 0 \\ 1 & 1 & 3 & 3 & (4) & 3 & 2 \\ 0 & 0 & 0 & 1 & 1 & 3 & 2 \end{bmatrix}$$

The cells that include 4 are the solutions of the image lines. These are surrounded with cells of 3,s and 2,s, where these results appeared because the transformed lines are congested around the solution point. To overcome this problem, the size of the intercept (C) must be scaled to become the size:

$$C = (M \times Y)+1.$$

This can be done by transferring every pixel of the image space using the equation:

$$c = \lfloor 3 (-mx + y) \rfloor$$

for every slope (m) from between -1 and 1 . The transform (H) of the two lines in (3) will become:

$$H = \begin{array}{ccccccc} (4) & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 2 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 1 & 0 \\ 1 & 0 & 1 & (3) & 0 & 0 & 1 \\ 0 & 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 2 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & (3) & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 2 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 0 \end{array}$$

The transform showed a solution cell including 4 for a line of slope -1 and two cells including 3 for the split digital line at zero slope. The cells that include one's and two's are the cells where the parameter space lines were passing. Thus with a parameter space of this size it would be recommended to neglect the cells that include ≤ 2 .

2.3 The Hough Transform in Car Registration Plate Recognition

In this project the Hough transform was used in two processes of the registration plate recognition. It was used in the character identification process as well as in plate tilt detection. The detail of the technique used for the process will be presented in Chapter 4, as this section will only show the theoretical background of these methods.

2.3.1 Image Identification using the Hough Transform

The image identification using the Hough transform is based on the following:

- The Hough transform will be applied to the character edges.
- There are two transforms for the edge lines; one for the group of lines that have slopes between -1, 1 (horizontal lines) and the other for the rest of the edge lines (vertical lines).
- After the completion of the transform, every solution cell within the parameter space includes a number equal to the number of pixels for the image space corresponding line .

- The solution cell location is defined by the slope and intercept of the transformed line.

Therefore any character edge image includes a number of lines, where these lines can be defined by the solution points within the two-parameter spaces:

$$\text{character} = \Sigma (L_h, L_v)$$

where L_h , L_v are the horizontal and vertical edge lines and these lines are function of their length and parameters

$$L = f(l, m, c)$$

Identifying a character by the full edge lines parameters presentation will produce a very good description for this character, but the size of this definition will be relatively large. For a simpler implementation for a character, the edge lines can be divided into groups and every group is identified by the number of lines within this group and their total length. The edge lines can be divided mainly into the vertical and horizontal lines, and then the identification can be extended by subdividing the two main groups into smaller groups according to the polarity of their parameters.

2.3.2. Plate Tilt Detection By Using Hough Transform

Because of the nature of Australian registration plates and the shape of the characters used in the plate, the majority of the edges of the plate around the horizontal direction are in the same direction as the plate. Due to this design, the tilt angle of the plate can be measured by analyzing the distribution of slopes for these lines, where the slope of the majority of the lines having the same plate tilt slope.

The measurements of the slope of the plate edges around the horizontal was achieved by applying a Hough transform algorithm to these edges and accumulate the solution cells for every transform angle. The slope that includes the majority of solution cells is the tilt slope.

2.4. Chapter Conclusion

From the theoretical study for car registration plate recognition systems, it was observed that these systems used different techniques in plate character recognition based on the full image feature matching (Lotfo, *et al.*, 1990; Fahmy, 1994; Lee, *et al.*, 1994 and Comelli, *et al.*, 1995). However, this study will demonstrate that the Hough transform can be used to produce an identification array for a character which depends upon the dimensions and shape of the character edges, and this identification will be used to recognize the registration plate characters. Because the identification array of a character would have much less elements than a character image matrix, it is expected that the recognition speed will be faster and the database memory will be reduced.

The car registration character recognition technique using the Hough transform to perform character identification was developed in this study. A system based on the development of this concept will be constructed and tested on a number of registration plates to evaluate the predicted success of the proposed technique.

CHAPTER 3

LITERATURE REVIEW

Car registration plate recognition has been carried out by applying a range of image processing techniques. This study has applied the Hough transform to provide the character identification for the plate recognition. Therefore, it was most important to review the Hough transform, image processing techniques and the previous research in car registration plate recognition systems as well as the various techniques used in the detection of the registration plate area.

3.1 Literature on Image Processing

Many authors such as Gonzalez and Wintz (1987), Haralick and Shapiro (1992), Giardina and Dougherty (1988) and Harrison and Jupp (1990) have reviewed image processing techniques. While the general image processing literature treats a broad range of areas in image processing, this study has focused on reviewing the areas of image processing techniques that have a direct relation to the automatic car registration plate recognition techniques and the research methodology.

3.1.1 Edge Detection

The edge in an image is the sudden or the reasonable gradual change from dark to light and from light to dark of the gray level intensity. It is also the change from one colour to another. The area of interest in this investigation is the detection of the edges of a black and white image (binary image), where the edge is described as the change from black to white and from white to black. The most common technique to extract the binary edge is by filtering the image with a suitable mask to calculate the gradient image of the edges. Sobel (1970) used a filter known as the Sobel operator that is composed of two 3 x 3 masks as shown in Figure 3.1:

-1	-2	-1		-1	0	1
0	0	0		-2	0	2
1	2	1		-1	0	1

Figure 3.1. Sobel edge detector masks.

When the first mask was applied to an image it detected the edge lines around the horizontal that have slopes between 1 , -1. The second mask detected the remainder of the edge lines. While the Sobel operator is more suitable for the linear edge detection, Frei and Chen (1977) used a set of nine orthogonal masks that has been considered as a general edge detector for any shape. Also the image edge can be detected by a morphological method such as Beucher's gradient.

3.1.2 Image Segmentation

Image segmentation is the process of dividing the image into a set of constituent parts, and the different techniques used were reviewed by Gonzalez and Wintz (1987), Haralick and Shapiro (1992) and Tou and Gonzalez (1974). The purpose of image segmentation is to extract any part of the image for further processing such as for description and/or recognition. Segmentation is usually based on discontinuity and similarity of the gray level or the colour within the image.

Thresholding: This technique is one of the most important tools for image segmentation and one of the earliest techniques, with some early papers treating this topic included those by Doyle (1962), Narasimhan and Fornago (1963) and Rosenfeld, *et al.* (1965). The principle of the technique is based on the gray level distribution within the image as it is usually composed of gray level bands. The segmentation is carried out by splitting out the area that has the same gray level bands from the remainder of the image.

Colour based segmentation: This process is another type of thresholding reviewed by Tou and Gonzalez (1974) based on several variables. Unlike the gray thresholding, which extracts an area of the image that has a certain range of gray scale intensity, the colour image segmentation is concerned in an area

that has a certain range of colour elements. For example, the images that are defined by the combined value of red, green and blue (RGB), then the segmentation will be based on the range of red and/or the range of green and/or the range of blue.

Region-oriented segmentation: This technique is based on direct segmentation by dividing the image into smaller parts and assembling the neighborhood areas that have the same features. The early development on region-oriented segmentation was by Muerle and Allen (1968) and Brice and Fennema (1970). This technique was reviewed by Zuker (1976), Fu and Mui (1981) and Gonzalez and Wintz (1987) where they established some unifying concepts of region-oriented segmentation and discussed the merits of various segmentation techniques.

Motion-based segmentation: Unlike the other segmenting techniques which process a single frame image, this system analyzes a series of time sequence frames captured by a fixed camera. By comparing these frames, the system can segment the part of the image that changed its position. There are two methods of segmentation which apply a spatial technique and a frequency domain technique. The spatial technique is described in the paper by Jain (1981, 1983), where this technique performs a simple approach for motion detection. It calculated the difference between two images on a pixel by pixel basis in both the x and y direction. If the change in any of the pixels was greater than a certain threshold, then the system segmented the area that has this change. The frequency domain technique is another motion-based technique developed by Rajala, Riddle and Snyder (1983). In this method the system detects the motion via the frequency change in Fourier transform of two consecutive images.

3.1.3 Image Recognition

In order to recognize any image it is first required to extract its features. Every feature can be labeled or described where these unknown features or description are compared to known features for identification. The result of this matching will provide full image recognition. There are many matching techniques that compare features, including:

Distance measuring: Tou and Gonzalez (1974) compared the description of a known image (x_1) with the description of an unknown image (x_2), by measuring the distance between the two description vectors

$$\begin{aligned} D (x_1 , x_2) &= \| x_1 - x_2 \| \\ &= ((x_1 - x_2)' (x_1 - x_2))^{1/2} \end{aligned}$$

The system measured the distances between the unknown vector and a group of known vectors, where the best match is the shortest distance.

Correlation: This is an efficient technique for image recognition, which was developed by Horowitz (1959). In this method the correlation coefficient is measured between a number of known images with the unknown image or part of an image of the same size. The highest correlation coefficient between the images is the best match.

Boundary matching: This method was developed by Sze and Yang (1981), where the matching was performed by comparing the contour string of known and unknown shapes.

Neural network: The neural network is a type of processing in memory where data is not stored in a particular place, but in different neurons that are connected to each other. It has the ability for self-learning in a method called associative learning. The neural network learns to produce a pattern of activation in a set of units whenever a certain pattern of activation is present to another connected set. The relation between patterns is called *pattern association*, and the pattern associator is the system used to create the association between these patterns in different subset. In general, a neural network is an attempt to produce a model that functions like the human brain, although there is no exact understanding about the way the brain functions.

Unlike conventional memory processing where the information is stored in a physical location as a block of data, in the associative memory the data is spread in connected neurons. In the access to data in conventional memories, the processor gives the address of data without any information about it. While in the associative memory the location of the required data is in the form of connected files and sub files where the address can give some information about the data and related subjects. For example, the address of the "apple" file could be through the "garden" and the "fruit" file (Cariling, 1992).

The training process of the neural network for image recognition based upon updating the database of the known features with new features of slightly different images. The update should be according to the weight or the number of times the database was trained. The training process increases the possibility of the correct recognition of an image while a variety of environments will affect it. The neural network for image recognition was pioneered by the work of Rosenblatt (1962), Block (1962) and Nilson (1965), where the network was trained to recognize the different possible patterns of a certain image. This training produced a connection matrix, which when an image was presented to the trained network will produce a related output.

3.1.4 The Morphological Analysis

This type of analysis was initiated by Georges Matheron in the late 1960's and reviewed by many authors such as Giardina and Dougherty (1988). This early work was on binary images and has been extended to cover the gray images. This analysis is based on the Minkowski algebra for the two values images in both Euclidean (analog) or digital forms.

The morphological operations can be used in many image processing applications including edge detection, thinning, segmentation and enhancement. Giardina and Dougherty (1988) explained the morphological approach which is based on producing a new image from analysis of two valued existing images; one is the main image and the other is usually much smaller. It is used as a filter to produce the desired new image, where the algebraic properties are based upon the Minkowski addition and subtraction. The morphological algebraic properties such as *erode*, *dilation*, *open*, *close*, *top hat* and other operations can be combined to produce the various image processing operations.

3.2 Literature on Registration Plate Recognition

Research on car registration plate character recognition has been conducted by Lotufo, Morganand and Johanson (1990), Fahmey (1994), Lee and Kim (1994), Comelli, Ferragina, Granieri and Stabil (1995) and Tindal (1995) using a variety of character recognition techniques for template matching by distance measure, cross correlation and neural network.

The theoretical techniques of the main methods used for car registration plate recognition were discussed in Section 2.1, so that this section will review the methodology of these techniques in the registration plate recognition. As it was shown in Section 2.1, these techniques were mainly a comparison between the full image and the different patterns of the database.

3.2.1 Registration Plate Recognition Using a B.A.M. Neural Network

A bi-directional associative memory (B.A.M.) is a neural network-based system and is based on two layer feed back neural network to encode patterns. The encoding or learning in a B.A.M. is carried out by modifying the weights between the neurons.

Fahmey (1994) used this concept in registration plate recognition where actual characters patterns were extracted from the registration plates in 16 x 16 pixels in binary image format, so that the value of every pixel was either 1 (for black) or 0 (for white). The B.A.M. system was trained by characters extracted from the actual registration plates and then developed an output of 6 x 6 matrix, which was unique for every character. When a character pattern was presented to the system, it produced an output matrix that was matched to one of the characters. The character pattern for the letters *A* to *Z* and numbers 0 to 9 were stored in multiple matrices, each together with their association (desired output).

3.2.2 Registration Plate Recognition by Using Cross Correlation Pattern Matching

The registration plate recognition process using cross correlation pattern matching was proposed by Comelli, Granieri and Stabil (1995). In this system the database was a group of prototypes for all letters and digits in a template in a reasonable gray level and in a standard size.

After extracting the registration plate from the whole image, it was normalized and scaled to the standard size of the plate. Considering that characters within the registration plate were uniform (usually have the same number of characters and these characters were located at regular fields in the plate), then the area of every character was scanned separately and recognized without the need for segmenting the plate into separate characters.

Registration plate normalization: Because of the requirement of the selected recognition technique, it is important to have the characters at a constant size and without any tilt. Comelli, *et al.* (1995) achieved these conditions by the plate normalizing process, which is performed in two steps:

- a. Estimating the character size and evaluating the registration plate tilt.
- b. Normalizing the plate according to this information.

Characters recognition: The standard sized character in the gray level image will be matched to all templates to measure the similarity. The system developed by Comelli, *et al.* (1995) applied a cross correlation technique between the sub-image where the character was expected, and the generic template that will result in a number of cross correlation values. The generic template that gives the maximum cross correlation is the solution.

The Italian plate used by Comelli, *et al.* (1995) in their study consists of two main fields: The left field presents the province initial; and the second to the right contains a six character string for the plate number. There are 95 character combinations for the Italian provinces for left part of the plate. Because of this format and the need to increase the registration plate recognition speed, the database of this system consisted of generic templates for digits 0 - 9, letters A - Z and the province initials (95 character pair templates). The size of the template is 20 x 17 pixels for single character and 20 x 50 pixels for the province template, while a plate extracted from a car image will be normalized to a 20 x 230 pixels image. Every sub-area will be cross correlated with its corresponding data base, so that the template that has the highest cross correlation will be the matching template.

Although the result of applying the method used by Comelli, *et al.* (1995) to the Italian registration plates was satisfactory (success recognition rate about 91%), it depended on the regularity of the characters distribution which is not the usual case in other registration plates. The database required a large memory, and the cross correlation for every pixel with a number of templates required a long processing time even with parallel cross correlation for all the plate characters.

3.2.3 Another Application of Neural Network Technique to Automatic Registration Plate Recognition

Tindall (1995) proposed this neural network system which become a market product. Tindal used a high speed digital camera to capture the image of a car, and this image was transformed by a digital signal processing module where the system searched for a plate like structure. If the system failed to find such a structure the image will be rejected, otherwise the registration plate will be extracted. Then a segmentation process was applied to the plate to separate the individual characters ready for recognition.

The registration plate character was recognized in this algorithm by using a neural network consisting of a multiplicity of interconnected nodes with gain factors or weights applied between each node. This network was trained to convert an input pattern to an output result. In this application the input is a two dimensional array of image pixels and the expected output should be the character of the input image. The training process for this network was achieved by inputting hundreds of character patterns of different qualities and the expected output for each of them would be declared by a human operator, the training of the algorithm modified the network weight to enforce the correct output solution. The network in this system was trained to recognize the different fonts, distorted and damaged characters images, and also rotated characters. More training to the network assists in obtaining better recognition.

Once the network completes its training it is considered to be stable and it cannot learn any more. After the training it can produce correct output response for any input image. Tindall (1995) and Tindall (1997) showed that this concept is applicable for the multinational registration plate with successful recognition rate over 95% of the extracted characters. Although this system proved reasonably successful in plate character recognition, it is still considered as a full image recognition which manipulates a two dimensional array which including the image pixels

3.3 Literature on Registration Plate Area Detection

There are many techniques used to detect the registration plate area such as the boundary following algorithms to detect the closest contour to the plate size that used by Lotufo, Morganand and Johanson (1990). Comelli, Ferragina, Granieri and Stabil (1995) detecting the maximum contrast area in the image to locate the registration plate. Lee, Kim, and Kim (1994) located the registration plate by using colour processing. Poon, Ghadiali, Man and Sheung (1995) used the gray scale morphological to locate the car registration plate. The following is a review of the main methods used for the registration plate area detection.

3.3.1 Detection Using Colour Image Processing

Lee, Kim and Kim (1994) used the colour based recognition process to detect the registration plate area from the image of a vehicle. The concept of extraction was based on the colour combination of a plate and its characters being unique in the plate region. The colour image processing used the HLI model that represented the colour in the values of the Hue, Lightness and Intensity. The Korean plates, which were detected, have the following colours:

- **White characters on green background**
- **Green characters on white background**
- **White characters on red background**

The system tested the image for each pixel with its eight neighboring pixels, as the surrounding colours are incorporated to influence the perception. Also this process caused local smoothing by blending irrelevant pixels into the large colour group.

The system scanned the image and transformed every pixel into one of four colour groups: red, green, white or any other colour. The horizontal and vertical histogram would extract the candidate plate in one of the three defining colours (red, green and white). The system can be trained for the different light conditions by using a neural network to function in the different working conditions. The probable plate area is tested with the plate structure feature, as the tested plate has a length to width ratio of 2.2 : 1. Thus the system examined the extracted segments to locate the area that has this feature.

3.3.2 Locating the Registration Plate Area Using Gray-Scale Morphology

This method is based on the morphological analysis reviewed in section 3.1.4. where Poon, Ghdiali, Man and Sheung (1995) used this technique to detect the registration plate area. In this system the extracted image of the vehicle was set to 128 gray levels, and considered the plate character in black (gray level 0) and the license background white (gray level 127). The following stages were used to achieve this goal:

Enhancing the image: In this step the algorithm applied the top hat transform to the image with a central point origin $n \times n$ square of a reasonable size. This process enhanced the image details and filtered the low frequency components in the image (to remove the components that do not include the area of interest).

Detecting the spacing between characters: The system converted the characters to solid rectangles by dilation and minimization for the image using reasonable length vertical line arrays and a horizontal line array of reasonable length. This process is repeated a number of times sufficient to ensure that even the inclined lines were converted to the horizontal and vertical components. The spacing between the rectangles was detected using a closing process to fill the vertical spaces and then subtracting it from the image.

Horizontal lines detection: The horizontal lines were detected by opening the original image using a proper horizontal line array. This process produced a non connected line. To extend these horizontal lines, a dilation process was used to overlap with the spaces.

Obtaining the registration plate area: Poon *et al* (1995) used the vertical spacing and the horizontal lines detected in the previous two steps to produce a new image of gray level proportional to the probability of the presence of the registration plate. Using a proper threshold the system will isolate the pixels that have a value above this threshold value, and detect the point (**p**) that has the maximum intensity in this image. From the point (**p**), the system scans the

image horizontally to the right until a zero intensity pixel is detected. The location of this pixel is considered as the right edge of the registration plate, and similarly from (p) to the left to locate the left edge. Then the system again similarly scans the image vertically from (p) up and down to locate the top and bottom edges

3.4 The Fast Hough Transform

The review of the Hough transform in section 2.2.1 showed that also it is an efficient tool in image processing, but it had a limited application because of the difficulties which arose through its use. Recent Hough transform research, specially in the algorithms of fast Hough transform, has been proposed by Vuillemin (1994) and Guil, Villalaba and Zabata (1995) where the algorithms use the equation $y = mx + c$ for straight line detection. The methods proposed have overcome the following problems that Hough Transform application had:

1. **Infinite slope :** The transform is carried out in two stages; firstly applied to the lines that have slopes between -1 , 1 by using the equation $y = mx + c$, and then transforming the lines that have slopes greater than 1 and less than -1 by using the equation $x = ty + b$ that have slopes (t) between -1 , 1.
2. **Memory size and calculation time:** Guil, *et al* (1995) used a FHT algorithm to detect the solution point in the parameter space by focalizing on them. The parameter space was divided into four quadrants, so that every quadrant was divided again to smaller four quadrants, and so forth until it reached a quadrant of a cell size. To detect a line in the parameter space it was not necessary to perform the calculation for every cell in the parameter space whether the line was passing through this cell or not. The system verified whether the line crossed a quadrant by measuring the distance between the centre point of the quadrant and the line. If it was greater than the distance between the centre and the quadrant borders, then this line was not passing through this quadrant and no calculation was required. But if the distance was less, then the system will go to the smaller sub quadrant and so on until it has found the cell that included the line. Vuillemin (1994) used another FHT algorithm similar to the fast Fourier Transform (FFT). This transform is carried out in a number of steps equal to the number of slopes angles required.

With these methods of the fast Hough transform it is possible to deploy this transform in a technique able to identify the plate characters. These identifications will be the foundation for the registration plate recognition, as it will be detailed in Chapter 4.

CHAPTER 4

THE STUDY

The project was conducted in three stages consisting of a feasibility study, a pilot study and the investigation. This chapter will describe the feasibility study and pilot study to indicate the viability of the research, and then the development of the registration plate recognition system to identify the Australian registration plates.

The study covers a complete registration plate recognition system for a colour image of a car, the system segments the image and extracts the registration plate area and normalize it. Then the system segments the registration plate to separate every character to be recognized by using the Hough transform technique. In the feasibility study the system was theoretically constructed. A limited test for the project algorithm was conducted in the pilot study to indicate the viability of the Hough transform method for character recognition prior to the development of the complete system. Finally this chapter will review the research methodology which presents a description for every stage of the project including character identification, registration plate detection, normalization of the plate, character extraction, database development, and character recognition.

4.1 The Feasibility Study

The review of previous research and the theoretical concepts of the project were the initial guideline from which the research methodology was developed. Thus the feasibility of the project was conducted to cover the following areas:

- Construction of the techniques that will be applied for every stage of the car registration plate recognition system.
- The hardware required for this research.
- The selection of suitable software for the processing of the images

In the feasibility study stage the system was theoretically constructed and the software and hardware required for the project were selected, as this work was a preparation to build the systems used in the advanced stages of the study.

4.1.1 Evaluating the Procedures of Plate Recognition

The automatic registration plate recognition procedure has been reviewed, and the following method is proposed for each processing stage. While most of the proposed systems were applied in the project methodology, some other systems were developed to suit the application.

Location of the registration plate: Registration plate images were recorded in three groups for a number of cars, with each group having plates of a certain size, so that testing for the different sizes of images for plates allowed the selection of the best size for the imaging procedures. The images were recorded by a video camera, with its shutter speed set to high speed to record the image for the back of the car where the registration plate was located. After the completion of recording of the required number of car images, the video camera was connected to a computer equipped with a frame grabber (video bluster SE100) to convert the colour analog images recorded by the camera to colour digital images. The digital images for the plates were stored in the memory in a bit map format ready for image processing. As the images used in this project were obtained from yellow registration plates with black characters, the proposed system was developed to search for the yellow areas in the car image and examine these areas to match the registration plate dimension features. Although the current system has been configured to detect only yellow background it could, equally well detect other specified colours of backgrounds. When the plate area was located, it could then be extracted for the optical character recognition process.

Normalizing of the registration plate area: At this stage of processing the system measured the tilt angle of the plate and rotated it in the opposite direction by the angle equal to the tilt angle. The system prepared the image of the extracted plate for this process by changing it from a colour to a black and white image. Then the system detected the horizontal edges of the black and white image of the extracted plate to measure the tilt angle. Because of the rectangular shape of the plate and its characters, the slope of the majority of a plate's horizontal edges all have the same plate tilt slope. Hence applying the

Hough transform algorithm to the plate's horizontal edge lines has produced solution points for a variety of slopes, but the majority of these slopes were in the direction of the plate. The system then examined the parameter space to find the slope that included the majority of solution points. This slope was the plate tilt, and assisted the system to determine if the tilt is zero, so there will not be a need to rotate the plate. Alternatively, the system rotated the plate image with an angle equal and opposite to the tilt angle.

Character feature extraction: The system extracted the characters in two stages, in order to recognize them. This was achieved by firstly extracting the "characters area" from the plate by searching the black and white plate image to find an area of black concentration. This process will extract the "characters area" from the border around it. The "character area " extraction is a primary extraction process to separate the top and the bottom parts of the registration plate, which may include marks that could affect the character extraction. The second step was the extraction of the individual characters by scanning the plate horizontally to locate the gaps between characters. Figure 4.1 is for the vertical colour concentration of plate character gap showing the gaps between these characters which will be the boundaries for character extraction. When the gaps have been detected from the scan then the system can isolate every character in the plate image.

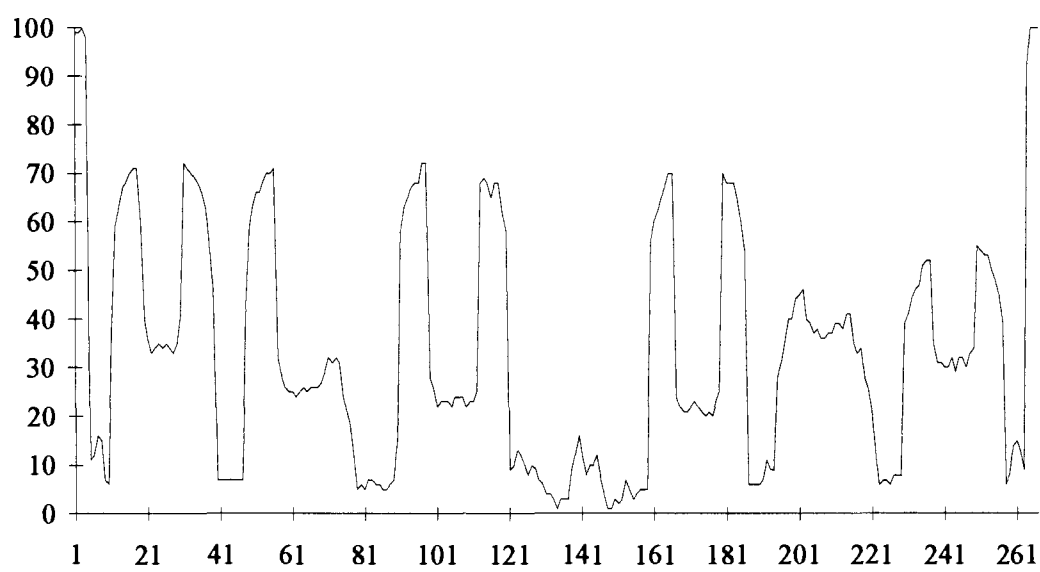


Figure 4.1: Vertical colour concentration of a plate character

Characters identification: In this system the character is identified by the number and the length of its edges, as determined by the Hough transform to detect the image edge lines. As it has been mentioned in Sections 2.3.1 and 3.4, the system has to detect the character's horizontal edges separately from the vertical edges. Therefore, a suitable algorithm that can separately detect each set of edges was developed.

Applying the Hough transform algorithm to the horizontal edges of the character image will produce a group of lines in the parameter space. These lines are stored point by point in the accumulated cells of the parameter space, where an empty cell meant that no lines has passed by this point. The cells where the contents have a value of one presents a part of a transformed line, and the cells that include a number greater than one are the solution. The empty cells and single line cells will be neglected, as they are not representing any solution point for a line in the image space. Only the solution points will be transferred to the identification matrix.

The total sum of the contents of the identification matrix produced from the transform of the character image of the horizontal edge will represent the total length of all horizontal edges (L_h) and the number of active cells of the identification matrix represents the number of those lines (N_h). A similar procedure was applied to the identification matrix produced from the transform of the character image of the vertical edges, where this gave L_v and N_v representing the length and number of vertical edge lines of this character. Any character can be identified by an array (L_h , N_h , L_v , N_v) which is unique to this character.

Construction of the database: The database was prepared from the identification of the registration plate character templates which have been manually separated for the digits 0 to 9, the letters A to Z, and the "dot" point which is used in the Australian registration plate. The edge detection algorithm was applied to the templates, and with the use of the Hough transform technique the system produced the identification arrays for the data base characters. The database, which has been formed, is a 37 x 4 matrix (Table 4.1), each row of the database matrix contains the four parameter character identification array.

Character recognition: The system performed the recognition process by calculating the error factor (E_{cn}) between the unknown character identification array and each database matrix row. In order to determine the error, let the identification array of the unknown character be $(L_{hc}, L_{vc}, N_{hc}, N_{hc})$ and the database matrix nth row which represents a certain character (n) identification array $(L_{hdn}, L_{vdn}, N_{hdn}, N_{vdn})$. The error factor between an unknown character and the nth row of the database (E_{cn}) is:

$$E_{cn} = |L_{hdn}-L_{hc}|/L_{hdn} + |L_{vdn}-L_{vc}|/L_{vdn} + |N_{hdn}-N_{hc}|/N_{hdn} + |N_{vdn}-N_{vc}|/N_{vdn}$$

The calculation of the error factor between the unknown character and each row of the database, and the minimum of these errors factors will be detected. If the minimum error was greater than a certain threshold then the character does not match any of the database characters and was not recognized by the system. Otherwise, the unknown character was recognized as the character that was represented by the array that produced the minimum error factor.

4.1.2 The Hardware Requirements

The hardware used in this project to identify the registration plate character as shown in the schematic diagram was:

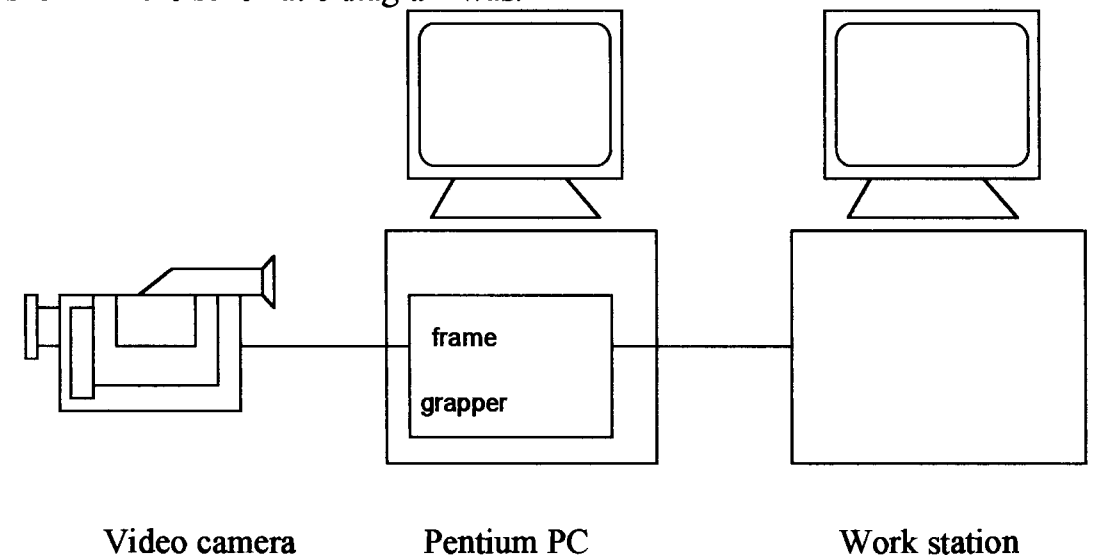


Figure 4.2. Schematic diagram showing the hardware organization.

- **Camera:** Sony CCD-TR750E (Hi-8): The video camera shutter was set to a high speed to record shots for car images.

- **Work station:** Sun Ultrasparc-170: This work station was equipped with Matlab software which was used to prepare the system program and run the system procedure. The Matlab software was applied on the work station for convenience of operation, while the complete system can be installed on a PC.

A Pentium 166 PC was used in conjunction with the frame grabber to convert the analog video image to bit map digital image. The reason for using two computer is because of the availability of software and hard ware required, but a single computer equipped with the proper software and frame grabber would be satisfactory.

- **Frame grabber:** Video bluster SE100 was deployed to convert the analog colour video signal to a digital image.

4.1.3 Choosing the Software

The analysis of the theoretical concept of the project (Section 4.1) indicated that the system required software that can process the following forms of data and information:

1. The computation of matrices for images analyses and Hough transform parameter space.
2. Image processing and graphics plotting.
3. Digital image processing.

The requirements stated in points 1 and 2 have been satisfied by the Matlab software specifications, where Matlab is a high-performance language for technical computing. This programming system was developed for matrix computing with complex mathematical functions. The Matlab image processing toolbox can process images and graphics for two-dimensional and three-dimensional data. Using Asymetrix digital video producer 3.0c satisfied the third requirement regarding the video capture.

When the video camera image was loaded into the computer though the frame grabber the Asymetrix digital producer was used to select the colour image presentation form to store these images. The Matlab software was applied to prepare the system algorithm that used to execute all the system procedures.

4.2 The Pilot Study

A pilot study was performed to examine the proposed system for recognition of registration plates, and to evaluate the efficiency of the theoretical application. For this stage of the project the database was constructed and algorithms to recognize the manually separated black and white registration plate image were developed for image recognition applications. The system was tested on ten registration plates manually extracted to test the robustness of the processing. The results of this stage of the project were evaluated to develop the system for the final assessment.

4.2.1 Preparing the Database

To prepare the database a selection of the images stored in the memory were enhanced and converted from colour to black and white binary images. From these plates the images of the digits 0 to 9, the "dot" point and the letters A to Z were manually separated from the binary images. The character templates were stored in the memory for identifying each character in the form of four elements array. The identification arrays for these templates were presented in a 37 x 4 matrix to form the system database that will be the reference for the plate character recognition.

In this stage of the study the algorithms for the database preparation were developed. These algorithms included the horizontal edge detection program, the vertical edge detection program, the horizontal definition program to produce the parameters L_h , N_h , and the vertical definition program to produce the parameters L_v , N_v . These algorithms were again used later in the plate character recognition process.

Both the edge detection method and the preparation of the identification parameters using Hough transform will be presented in detail in Section 4.3. The system used these processing techniques to produce the database from the characters templates as shown in Table 1.

Table 4.1

Hough Transform Identification of Registration Plate Characters

Character	L_h	N_h	L_v	N_v
0	39	4	173	4
1	16	2	120	2
2	79	7	128	20
3	52	8	110	10
4	43	4	230	25
5	94	12	120	10
6	58	8	156	15
7	49	3	113	17
8	63	10	204	15
9	61	9	142	12
A	40	4	271	45
B	74	8	243	20
C	61	8	117	9
D	44	6	225	18
E	102	8	124	7
F	93	7	117	5
G	85	10	180	15
H	51	5	248	13
I	34	4	130	9
J	36	5	128	5
K	31	3	318	38
L	51	4	117	4
M	29	3	465	55
N	24	2	434	54
O	64	8	217	15
P	64	7	161	9
Q	*	*	*	*
R	60	6	242	22
S	70	9	129	15
T	46	3	116	4
U	37	4	263	19

Table 4.1 (cont'd)

Character	L_h	N_h	L_v	N_v
V	*	*	*	*
W	37	5	186	21
X	24	3	368	59
Y	*	*	*	*
Z	91	4	136	21

Note. the parameters marked with '*' for data were not obtained at this stage because these characters are rare in the Western Australian registration plates.

Each of the alphabetical and numerical characters has been shown to be unique in the term of the designated formats, but because of the limited nature of the pilot investigation, several characters were not surveyed.

4.2.2 Testing the System on Manually Extracted Plates

The plate area was manually extracted from ten full images of registration plates for preliminary trials in order to evaluate the effectiveness of the Hough transform for the identification of characters.

The system prepared the plate for the recognition of characters in the following steps:

- (a) Conversion of the colour image of the plate to a black and white binary image to render the image suitable for the further processing.
- (b) Extraction of all characters in the area from the plate image. The extraction procedures used in this study were to detect the area of maximum intensity. This process was performed in two steps; firstly with the vertical separation to separate the registration number area from the top and the bottom part of the plate, and then the horizontal separation to separate the registration number area from the side borders (Figure 4.3).



Figure 4.3: Extracted characters area from the plate

- (c) The separation of the individual characters from the characters' area for identification: After separating the character area from the registration plate image, a similar procedure was used to separate the characters.
- (d) The detection of the horizontal and vertical edges for each plate characters, which can be used to produce the identification array.

These procedures for the extraction of the characters and character edge detection were most important in order to prepare the characters for the identification and recognition processes (Figure 4.4 and Figure 4.5 showing the detected horizontal and vertical edges for character "H").



Figure 4.4. Horizontal edges of a character



Figure 4.5. Vertical edges of a character

Then the application of the Hough transform to the edges of the extracted characters was able to produce the character parameters. The system compared the identification of the character with the database, and the character will be recognized as the highest match to the database.

4.2.3 Evaluating the Pilot Results

The evaluation of the results of pilot study was focused on character extraction from the plate image for identification and character recognition.

Extraction of characters from the plate showed an acceptable result (82% of the total characters were successfully extracted). The following are the reasons of unsuccessful extraction cases:

- The system failed to satisfactorily extract the characters adjacent to the side of the plate, especially with the plates that were surrounded with dark colour frames covering part of the side character or connected to it.
- Due to some dirt on the plate between any two consequent characters, the system extracted these two characters together, this usually happened when the high of the dirt area was greater than the threshold.
- The system extracted a side of the plate frame by considering it as a character; this happened when the registration plate area had ends with black lines and yellow surroundings.

The character recognition was only for 35% successful recognition of the total number of the characters within the tested plates, and the analysis of the results showed the following reasons that contributed in the wrong recognition:

- The registration plate environments and the method used to convert the colour plate image to binary black and white image created a distorted

image for the character with a slightly different shape to the data base template. This deformation changed the character edges that produced a different set of parameters for this character for identification in the database.

- As the car images were recorded from slightly different distances, then the registration plates were not of the same size. Due to this occurrence the identification parameters that depends on the character dimensions (L_h, L_v) were not correct.
- The results of the pilot study showed that the four-parameter identification used is not sufficient for specific character recognition especially when the character has been distorted.

Solution of the problems that faced the system during the pilot study in character extraction was obtained by the following techniques:

- Using a threshold equal to 90% of the 'dot' point height to detect the boundaries between the characters for characters extraction process will solve most of the dirt problems.
- In characters area extraction the system neglects the fields of vertical colour concentration less than a threshold of 90% of 'dot' width size (the 'dot' point size was used as a reference because it was the smallest character in width and height). This procedure will solve the problem of the extraction of plate frame side, considering it as a character.

Also for character recognition the system was modified to solve problems that faces the system in the pilot study such as:

- Converting the colour image to a gray intensity image and then converting it to a black and white image using a suitable threshold instead of the direct conversion. This procedure reduced the distortion in the binary image.
- Using a standard size template for characters with a standard size border. Also the extracted characters resized to the standard size and fitted into the same size border. This technique improved the rate of correct recognition.
- Increasing the number of the parameters in the identification array made the identification more descriptive. Also training the system with more templates improved the recognition results.

These techniques were used to develop the system and avoid the problems which appeared in the pilot study results. The detail of the system techniques will be discussed in Section 4.3.

4.3 The Methodology

The systems developed in the Feasibility Study (Sections 4.1.) and Pilot Study (Section 4.2.) showed positives and negative aspects. According to the results of the primary testing discussed in Section 4.2.3 some of the applied procedures were suitable for the project application while the others required modification to improve their functions.

The following Section will include systems, which were previously developed in Sections 4.1. and 4.2. after the required modifications. These will also include the development of the project areas that were not covered during the Feasibility Study and the Pilot Study. The sequence of the methodology review will not be the same as the recognition process, as the character identification process will be presented first to show the main concept of the project, followed by the other processes.

This section only includes a discussion for the system methodology without showing any of the algorithms used for this application. The project algorithm subroutines included in appendix B will cover all the project stages and their methodologies that will be discussed through the following Sections.

4.3.1 Character Identification

The character identification process was carried out for the horizontal and vertical directions of the image. The procedures for each direction were performed as follows:

- (i) Character image preparation by resizing the character and fitting it in a standard size border.
- (ii) Edge detection for the character in the vertical or horizontal direction.
- (iii) Producing the character identification parameters for the character edge lines detected in step (ii).

The system combined the vertical identification parameters with the horizontal identification parameters to form the identification array.

Character image preparation: The Pilot Study demonstrated that incorrect recognition occurred for some characters in the recognition process was due to the difference in size between the character size and the database character template size (Section 4.2.3). Thus it was important to adjust the character image size to a standard size similar to the database characters size. Also because of the requirements of the extended identification which will be discussed later in the current section, the system required the character to be in a standard size border for correct processing.

Edge detection: Edge detection for the black and white binary image extracted characters is an important process prior to character identification. Hence it is most important to choose an edge detection method suitable for the identification technique. The Guil, *et al.* (1995) method to solve the infinite slope problem reviewed in Section 3.4. required the splitting of image lines into two groups, a group for lines of slopes between 1 , -1 and the other group for the remainder of the image lines. The Sobel operator (Sobel, 1970) is an ideal technique in this aspect, as it produces these groups by applying Sobel masks. But there were two problems involved with the application of the Sobel operator:

- (a) Applying the Sobel operator will create a two lines edge with an edge in the character side and the other in the background side. This will require a thinning algorithm to reduce the edge to only one line. Thinning the edges can be achieved by vertically scanning the horizontal edge image produced as result of applying the Sobel operator, and by horizontally scanning the vertical edge image to combine the double lines into a single line.
- (b) Filtering the image by a Sobel mask is done by numerous calculations for to filter every pixel as it required nine multiplication and one addition procedure, with this process being repeated twice for each direction (vertical and horizontal). Therefore, it requires considerable processing time for detecting every character edge within the plate, as well as the processing time required for the thinning algorithm.

As a consequence, the time consumption problem caused by using the Sobel operator will slow down the recognition process. Therefore, another technique has been developed which was more suitable for binary image edge detection as it required a lesser number of calculations in the processing, and so become faster than by using the Sobel operator.

The edge detection technique adopted in this study is a simple algorithm that scans the binary image horizontally and detects any change from 1 to 0 and 0 to 1, where those changes will produce the vertical edge. Again a similar procedure was applied to detect the horizontal edges in the binary image.

Producing the character identification: At this stage the Hough transform was used for character identification, with the method of Guil *et al.* (1995) as in Section 3.4. to solve the problem of infinite slopes. The character identification was performed in two steps with normal Hough transform for the horizontal edges and then by rotating the vertical edges through 90° in applying the equation $x = t*y + b$ for the Hough transform to the vertical edges.

The difficulty of parameter dimensions discussed in Section 3.2.2, where an incorrect solution produced by using a parameter space of the same size as the image space. This problem is created when adjacent points in the image space were transformed into lines in the parameter space, so that the produced lines will be very close to each other. As the parameter space cell address is an integer number, then an approximation is required to obtain the integer number for the cell locations. This approximation will require some points of a line to share the same cells with other points of another line especially around the solution point. As the processing technique is designed to detect the cells that include a number greater than one, therefore the system will consider the shared points as solution points and will give false results and do not present the actual number and length of the character edge lines.

The parameter space used in this research is designed to be of the following shape: the slope (m or t) $\in \{ -3, -2, -1, 0, 1, 2, 3 \}$ and intercept (c or b) equal to six times the space image ordinate axis in horizontal process or six times the image space abscissa axis (three for the positive and three for the negative) for the parameter space height.

Character identification was achieved by applying the Hough transform algorithm to the horizontal edges of the character image, and producing a group of lines in the parameter space. These lines will be stored point by point in the accumulated cells of the parameter space, where an empty cell meant that no lines passed by this point, and the cells that have only one line represents a part of a transformed line. The system neglected the cells that include a value less than three as they don't include a solution, where the rest of the cells will be transferred to an identification matrix of the same size.

The total sum of the contents of the identification matrix produced from the transform of the character image of the horizontal edge, will represent the total length of the horizontal edges (L_h) and the number of active cells of the identification matrix represents the number of those lines (N_h). A similar procedure will be applied to the identification matrix produced from the transform of the character image of the vertical edges, so that this will give L_v and N_v respectively, representing the length and number of vertical edge lines of this character. Thus any character will be identified by an array (L_h, N_h, L_v, N_v) which is unique to this character.

The preliminary trials were conducted during the Pilot Study on typical Australian car registration plates in order to evaluate the effectiveness of the research method for identification (Section 4.2.). A limited number of vehicle registration plates were recorded on video, and digitized images were produced for recognition and analysis of the results. The recognition results of the pilot study in Section 4.2.3. showed that the result of the correctly recognized characters was 32% which was not a satisfactory results. One of the reasons contributed in the poor recognition was the relative similarity of some identifications such as N and M, C and O, X and N, T and I, 3 and C and some other pairs of characters (Table 1). Therefore, it was necessary to create a more descriptive identification procedure.

When a character edge image Hough transformed into the parameter space (Figure 4.6) it will produce solution points in any quadrant of the parameter space.

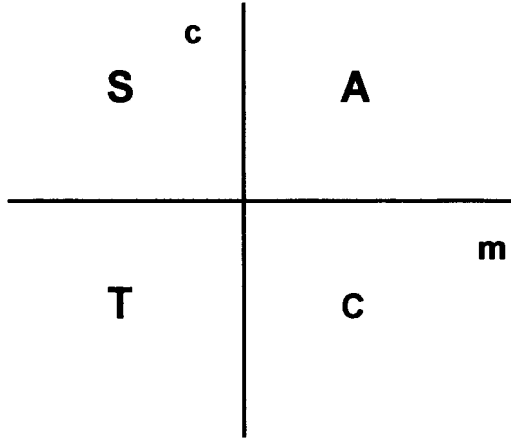


Figure 4.6. The quadrants of the parameter space.

Therefore it is possible to separate the points of every quadrant to extend the identification array to the form:

$$[L_{ha}, L_{hs}, L_{ht}, L_{hc}, N_{ha}, N_{hs}, N_{ht}, N_{hc}, L_{va}, L_{vs}, L_{vt}, L_{vc}, N_{va}, N_{vs}, N_{vt}, N_{vc}]$$

where:

- $[L_{ha}, N_{ha}, L_{va}, N_{va}]$ is the identification array of the solution points in the A quadrant.
- $[L_{hs}, N_{hs}, L_{vs}, N_{vs}]$ is the identification array of the solution points in the S quadrant.
- $[L_{hc}, N_{hc}, L_{vc}, N_{vc}]$ is the identification array of the solution points in the C quadrant.
- $[L_{ht}, N_{ht}, L_{vt}, N_{vt}]$ is the identification array of the solution points in the T quadrant.

The database for the extended identification shows that there are no solution points for the vertical transform in the C-quadrant (the elements L_{vc} , N_{vc} were equal to zero for all characters) and for the horizontal transform in the T-quadrant (the elements L_{ht} , N_{ht} were equal to zero for all characters). The reason of this phenomenon is because the image is in the positive part of the image space therefore the lines that has a negative slope will never have a chance to intersect with the negative part of the y axis. The analysis of the transform results will be presented in Chapter 5.

According to the absence of the solution in one of the quadrants, it is possible to reduce the number of parameters for the extended identification by neglecting these parameters, and so the extended identification array can be in the form:

$$[L_{ha}, L_{hs}, L_{hc}, N_{ha}, N_{hs}, N_{hc}, L_{va}, L_{vs}, L_{vt}, N_{va}, N_{vs}, N_{vt},]$$

This identification array was used in the preparation of the database and was applied to the identification of the character prior to the recognition stage.

4.3.2 Registration Plate Area Detection

The group of car images used in this project had yellow backgrounds with black characters displayed on them. Colour image processing method was used to segment the registration plate of the car image by locating the area of yellow colour within the image. This was achieved by using the Matlab indexed colour image for coloured image representation where the image consisted of an image matrix and colour map, as this colour representation was suitable for the project application.

The MATLAB image processing functions and image processing toolbox were used in the research methodology of this study and included the use of the four basic types of images which were:

- a. Indexed Images that used to present the colour images.
- b. Intensity Images, which is used to show a non-colour, image with different gray scales.
- c. Binary Images is presenting the image only in black and white.
- d. RGB Images is another form of colour image presentation.

An indexed image consists of two arrays that are the image matrix and the colour map. The image matrix contains integers for every pixel, where this value is an index into the colour map. The colour map is an (m x 3) matrix where each row of this matrix specifies the red, green and blue values for a single colour as:

$$\text{colour} = [R \ G \ B]$$

R, G and B are real scalars that range from 0 (black) to 1 (full intensity). The image pixel will be shown by applying the intensity of every colour in the

colour map indexed by the value in the image matrix corresponding to this pixel.

The intensity image is presented in a single matrix, where each element of the matrix corresponds to one pixel. The matrix contains values in the range between 0 and 1, where the 0 intensity represents black and 1 intensity represents the white. The values between 0 and 1 indicate the gray scale intensity of this pixel. The intensity image pixel will be shown by applying the amount of light proportional to the value in the image matrix, where 1 is the maximum light and zero is no light.

In a binary image, the single two-dimensional matrix includes one of only two discrete values. The two values correspond to "on" and "off", where 0's are used for the "off pixels" and 1's for the "on pixels". Therefore, a binary image will contain only black and within its format.

Similar to the indexed image, each pixel in the RGB image is represented as a set of three values. Those values are for the red, green and blue intensities that combined together to produce the colour of this pixel. In this system the colour components (red, green and blue) of an image combined in a single three dimension matrix, with its size is [$m \times n \times 3$], where m and n are the number of rows and columns of the image. The third dimension consists of three planes containing the intensity values of the red, green and blue. Each pixel located in m , n of the image has a colour combined of the red, green and values in the third dimension. To show a pixel, the contents of the third dimension array will produce the colour of this pixel.

Color detection in a colour map: The colour system used to present the colour images in the study is the indexed image where the image is represented by an image matrix and a colour map. To detect a certain colour, the system had to search the colour map for this colour. In this study the system searched the full image looking for an area which included the yellow colour to locate the registration plate area.

The colour image of the plates can have various degrees of yellow especially for old and dirty registration plates. Therefore, the scan search for the plate will need to include a wide range of different shades of the yellow colour. However, because the yellow colour is not an indexed image prime colour,

then the search will be in a range of the three primary colours of red, green and blue so that the required range of yellow is available.

A series of tests of a large variety of registration plates in different conditions of age and cleanliness, showed that the search should be for the following:

- Red intensity range between 0.35 and 0.78 of full intensity.
- Green intensity range between 0.35 and 0.78 of full intensity.
- Blue intensity range between 0.1 and 0.4 of full intensity.

It should be noted that the difference between the red intensity and green intensity must have value less than 0.3.

With the appropriate range of settings for the colour, the system scanned the colour map looking for the rows that fulfill the conditions to select the variation in yellow registration plates (the same procedure can be applied to any other colour background). Then the row number for those selected rows will be the base for locating the registration plate.

Plate location: In the indexed image for each pixel, the image matrix contains a value that is equal to the row number in the colour map and according to the RGB values in the colour map row, the system presented the colour of this pixel. For the location of the registration plate, the system will begin searching in the image matrix for the pixels that include any of the values of the yellow range which was previously appointed. Another matrix of the same size as the image matrix will be constructed to include the segmentation result, and it will be filled with 1's and 0's, where one's for the location corresponding to the pixels that include any of the selected rows values, and zero's otherwise. This matrix will be called the Extracted Plate Matrix. The system will scan the extracted plate matrix horizontally to detect the beginning and end of columns of the area filled with ones, and similarly scan vertically to detect the beginning and end of rows.

Having detected the location of the plate extracted area, then the system becomes able to extract the registration plate from the image matrix according to this location (Figure 4.7 shows an extracted plate area according to the extracted plate matrix). The extracted plate image matrix and the colour map of the full image will be transformed to a binary image for further processing.



Figure 4.7: An extracted plate area

Direct transformations of the colour image to binary using a reasonable threshold to create a plate with a black background (zeros) and white characters (ones). This technique did not always give the solid black and the solid white in the image, and this was due to the statistical based threshold depending upon the map row which could vary from one image to another. The alternative method was to run this process in two steps, by firstly converting the image to an intensity gray image, and then by using a threshold proportional to the average intensity value of the gray image of the plate, so that the system can transfer the gray plate image to binary form.

The preliminary results of using the above mentioned technique for registration plate extraction failed to extract some of the plates correctly, and the analysis of this results showed that most of these plates were brighter or darker than the average, and so this system was modified

Examining the extracted plate area candidate structural features: The experimental results showed that the horizontal to vertical ratio of the correctly extracted plate is between 2.5 to 1 and 3.2 to 1. Therefore, the system examined the horizontal to vertical ratio of the extracted plate area candidate, if it was within this range system consider it as a correct extraction, otherwise it is a wrong extraction.

Plate area extraction for dark and light colour plates: If the system failed to extract the plate region, the system would darken the image by reducing the values of the colour map values by 20% of its values. Then the system would try again to extract the plat area. If the plate area was not properly extracted the system would lighten the image by increasing the values of the colour map values by 20%. Then the system would try again to extract the plate area, and if the plate area was not properly extracted then the image will be rejected.

4.3.3 Normalizing the Plate

The preliminary test phase of the investigation showed that character identification will change with both tilting of the plate and varying the sizes of the plate. Therefore, it is important to normalize the plate before segmentation and identification. In order to normalize the plate it was considered necessary to detect the tilt angle of the segmented plate. Applying the Hough transform to the plate horizontal edges of the plate, will assist in measuring the plate tilt angle. When the tilt angle of the plate has been detected then the system can normalize the plate to allow further process to occur.

When the plate has been located and transformed to its binary image form, the system will separate the horizontal edges of the plate image using the same technique discussed in Section 5.3.1. by scanning the binary image of the plate vertically and detecting any change from 1 to 0 and 0 to 1, with the result of the edge detection of the plate image shown in Figure 4.8.

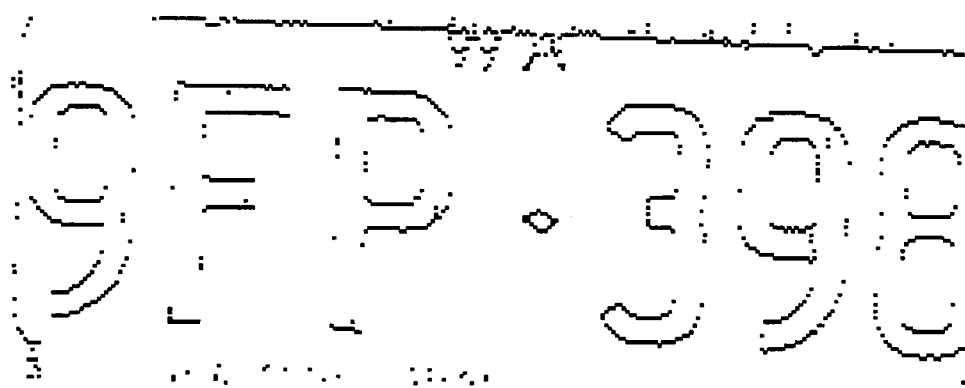


Figure 4.8: Horizontal edge of a tilted registration plate.

Then a Hough transform algorithm will be applied to the plate horizontal edges, and the output from the transform will be stored in a special parameter

space prepared for this purpose. The range of the parameter space tilt angle used in this project was between -11.31 degrees and +11.31 degrees which gave the range of the slopes between -0.2 and +0.2. The reason for this range was to reduce the processing time as it was expected that the tilt would not be outside this range. The dimensions of the parameter space for this transform was constructed to be of a number of rows equals to twice the number of the edge image rows and of 21 columns width. The number of columns will allow the system to detect any slope change for multiples of 0.02 (about 1.14 degrees) of slope.

Because of the design of the Australian registration plates, the majority of the edge lines and the solution points will have a slope to the horizontal axis equal to the tilt of the plate. For efficiency of the angle detection technique, the technique neglected the short lines (accumulator cells that have contents less than 60), to avoid the distortion from the details of the characters within the plate and to reduce the processing time. The remaining solution points of the parameter space will be accumulated for every slope column of the parameter

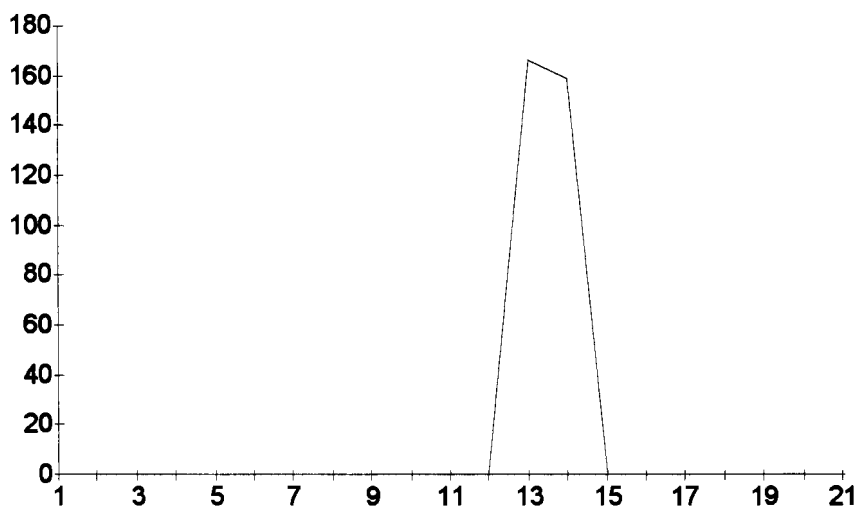


Figure 4.9: Tilt angle distribution for a registration plate

space to form a slope distribution for the plate edge image. Figure 4.9 shows the slope distribution histogram for the plate horizontal edge image of Figure 4.8.

The distribution histogram (Figure 4.9) has the following properties:

- The negative slopes were from 1 to 10 (location number 10 is -0.02 slope or a tilt angle of -1.13 degrees, and location number 1 is -0.2 slope or a tilt angle of -11.31 degrees).
- Location number 11 in the distribution has a slope of zero.
- The positive slopes are from location number 12 to 21 (location number 12 is 0.02 slope or a tilt angle of +1.13 degrees and location number 21 is 0.2 slope or a tilt angle of +11.31 degrees).
- The distribution curve is in a band around a peak at the plate tilt angle.

The peak of the slope (m) is the tilt angle of the registration plate. The slope (m) corresponds to an angle (θ) in the following relation:

$$\theta = \tan^{-1}(m)$$

This angle could be positive or negative according to the tilt direction, and the algorithm will use the angle to normalize the plate.

If the tilt angle (θ) was zero then there was no need to rotate the plate otherwise, the image will require normalizing. The normalization of the plate was achieved by rotating the full image instead of rotating the plate image to avoid any distortion, which could occur to the edge of the plate image due to the rotation that then may affect the identification. Therefore, the processing technique rotated the full image of the car containing the registration plate through an angle equal to $-\theta$. Then the techniques used in Section 4.3.2 to locate the registration plate will be applied to the rotated full image of the car and the normalized plate image will be extracted.

4.3.4 Characters Extraction and the Preparation for the Identification Process

After the registration plate was extracted and normalized, the extracted colour plate image will be transformed to a binary image format (Figure 4.10) as it was explained previously in Section 4.3.2.



Figure 4.10. The binary image of a registration plate

At this stage the registration plate image becomes ready for the individual character extraction and preparation processes which were conducted in the following steps:

- (a) Extraction of all characters area from the plate image.
- (b) Separation of every character from the characters area.
- (c) Extraction of the separated character from its border.
- (d) Resizing of the character and fitting it in a standard border.

These procedures are necessary to prepare the characters for the identification and recognition process.

Most of the Australian registration plates (Figure 4.11) include some small characters at the top of the plate for the State identification and occasionally a small characters at the bottom of the plate for special comments. In the middle portion of the plate is the registration characters large font size and this area is region to be separated.



Figure 4.11: A typical Australian car registration plate.

The extraction procedures used in this study are designed to detect the area with a majority of colour concentration. This process is carried out in two steps:

- (1) Vertical separation is achieved by summing the contents of all rows of the binary image of the registration plate. These procedures will give an array, which included values of the colour concentration of every row of the image. The histogram in Figure 4.12 showed the distribution of this array and it is clear from the diagram that the top and bottom parts of the plate have different peaks from the characters area.

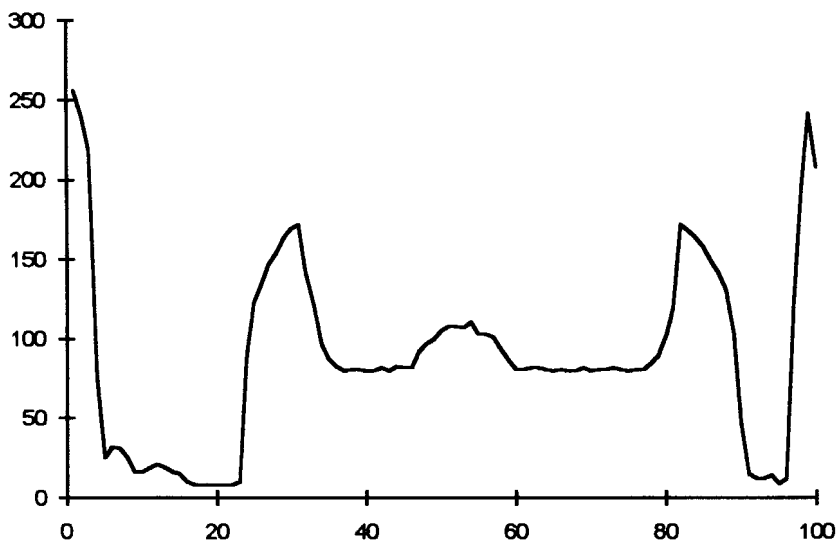


Figure 4.12. Horizontal colour concentration of plate characters

Using a suitable threshold will allow the image processing procedures to separate the registration number area from the top and the bottom part of the plate. Figure 4.13 shows the registration plate after separating the top and bottom parts of it.



Figure 13: Registration plate after separating the top and bottom parts.

- (2) Horizontal separation was achieved same as in the vertical separation, where the columns of the vertically separated binary image were added to form an array that included values of the colour concentration of all image columns. The histogram in Figure 4.14 shows the distribution in this array for a registration plate binary image before the vertical separation, where the boundaries between the characters are not clear.

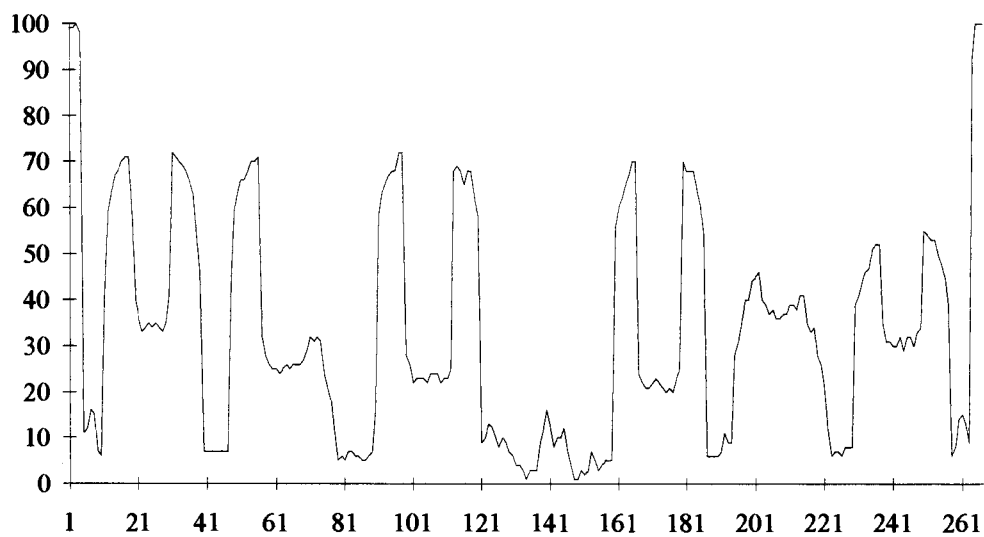


Figure 4.14: Vertical colour concentration of plate characters

After separating the top and the bottom parts of the registration plate image the boundaries between the characters become more obvious as shown in the distribution histogram (Figure 4.15), which also shows that the side borders of the plat image. Again, by using a suitable threshold the system will allow the separation of the registration number area from the side borders.

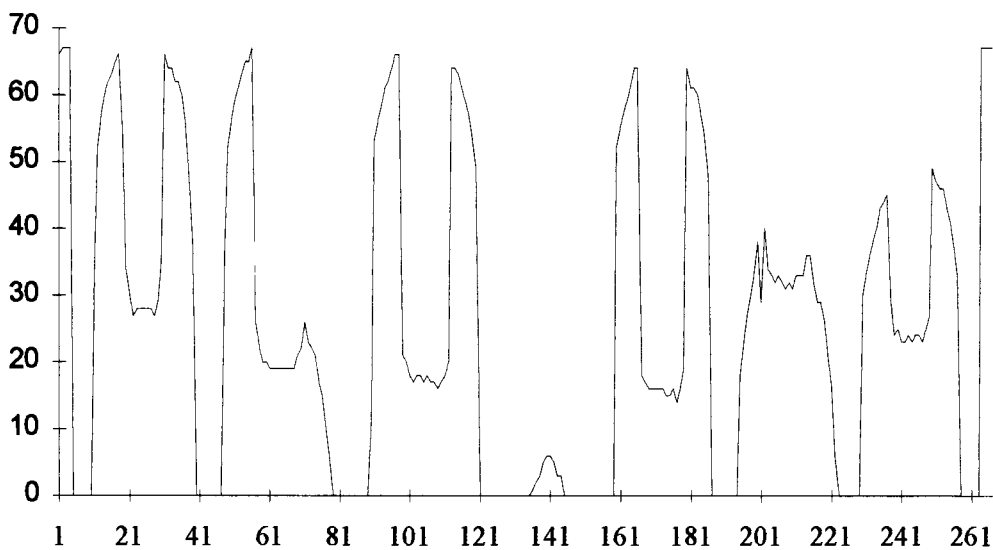


Figure 4.15: Vertical colour concentration of plate characters after the vertical separation

Figure 4.16 shows the registration plate after segmenting the character area which allow the system to separate the characters and to recognize them.



Figure 4.16. Registration plate after the vertical and horizontal separation

Separating every character from the characters area was achieved by applying similar procedures to those used to separate the characters area. Summing the

contents of every column of the separated character area image produced a distribution of colour concentration that increased at the characters location and decreased at the spaces between the characters as in the distribution histogram (Figure 4.17).

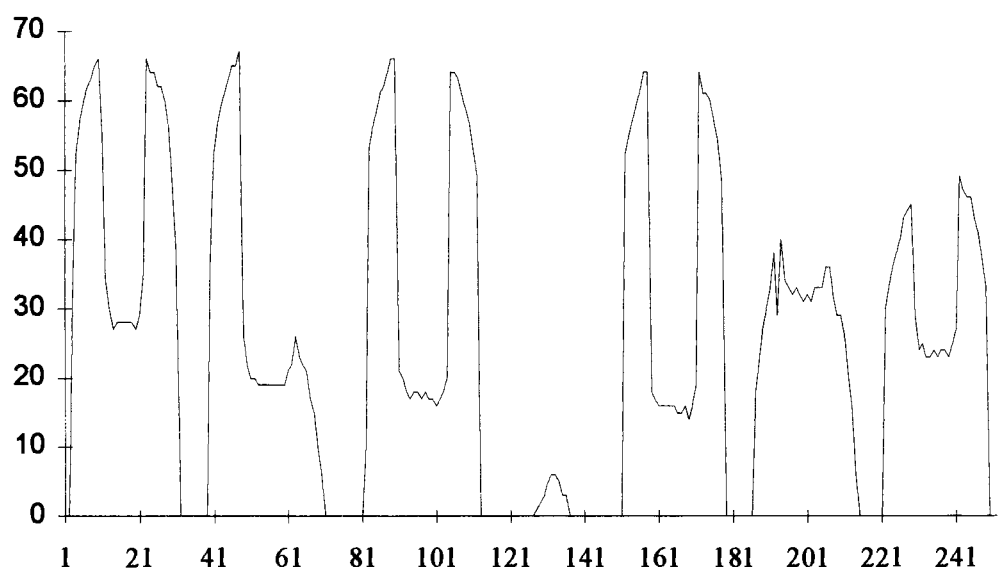


Figure 4.17: Vertical colour concentration for the extracted character area

By choosing a reasonable threshold, the system examined the array that was produced from the addition of the image columns, and detected the values less than this threshold within the array. Those parts of the array that correspond to the boundaries between the characters allow the system to segment the character area image and to extract the characters that exist between a middle point of a boundary and the middle point of the next boundary. The procedures also determine the left and right of the image as the first and the last boundaries.

The extraction of characters located in the middle of the boundaries produced characters with irregular borders, so that the system extracted the characters from their borders by applying the same technique used for separation of characters area. The system firstly separated the top and bottom borders using the vertical separation, and then separated the side borders using a similar horizontal separation.

Because the registration plates were not of the same size, the identification parameters that depend on the character dimensions (L_h L_v) will not be constant. Also, the shifting of a line in the image space vertically or horizontally changed the value of the intercept (c). As it was shown in Section 4.3.1, the extended identification parameters for a character depended on the polarity of the intercept, and the intercept could be in a different polarity if the border size changed. Therefore the processing produced a standard sized character in a standard border ready for the identification process.

The images tested in the pilot study showed that the range of height of characters was between 50 and 70 pixels for all the characters except the "dot", which had a height of approximately 15 pixels. If the extracted image height (h) was greater than 30 pixel, then the system will resize the character according to:

$$\text{Resized image} = \text{the extracted image} \times 60/h .$$

The resized characters have been fitted with a border of five pixels surrounding it. Otherwise if the height was less than 30 pixels then the system will resize the "dot" with a different ratio:

$$\text{Resized image} = \text{the extracted image} \times 10/h .$$

The border was required to produce a standard "dot" template of ten pixel to each side and thirty pixel to the top and the bottom.

4.3.5 The Character Identification Database

In this stage of the study the image processing produced a new database from new templates after it had resized and fitted a standard border for the old templates used in the pilot study. Unlike the database in Table 4.1 in Section 4.2.1, where the character identification contained a four-element parameter, the new database has the character identification extended to become a twelve-element parameter for better description of characters. Also, this database was trained to become more flexible and had better recognition.

The initial database was produced from the templates of letters A to Z, the digits 0 to 9 and the "dot" point, and these characters were resized and fitted in a standard borders. Extended character identifications were produced for these characters and formed a 37 x 12 array showed in Table 4.2.

Table 4.2
Extended Character Identification Database.

Charact.	L _{ha}	L _{hs}	L _{hc}	N _{ha}	N _{hs}	N _{hc}	L _{va}	L _{vs}	L _{vt}	N _{va}	N _{vs}	N _{vt}
0	0	0	41	0	0	5	193	130	104	12	32	26
1	0	0	14	0	0	2	108	0	0	2	0	0
2	4	13	70	1	3	7	118	117	8	21	5	2
3	5	0	53	1	0	10	124	62	12	15	15	3
4	0	0	39	0	0	4	145	140	53	15	27	13
5	0	4	88	0	1	13	106	14	52	9	3	2
6	0	17	44	0	4	7	125	60	50	12	14	12
7	0	0	43	0	0	3	103	70	4	14	16	1
8	4	4	73	1	1	14	170	73	42	12	17	10
9	9	13	62	2	3	11	148	63	51	16	15	12
Dot	0	8	4	0	2	1	0	8	0	0	2	0
A	0	0	42	0	0	6	201	113	83	30	24	19
B	0	4	80	0	1	11	200	103	67	16	23	15
C	8	8	57	2	2	8	100	22	23	8	5	5
D	23	0	43	5	0	7	218	162	82	21	39	20
E	0	0	94	0	0	9	102	29	4	5	7	1
F	0	4	80	0	1	7	105	20	4	5	5	1
G	9	4	67	2	1	8	148	32	56	12	8	12
H	0	0	45	0	0	5	205	79	92	9	19	22
I	0	0	33	0	0	5	110	32	8	7	7	2
J	0	0	44	0	0	7	114	41	11	5	10	2
K	0	4	27	0	1	3	238	126	89	26	25	20
L	0	0	45	0	0	4	105	0	12	4	0	3
M	0	0	47	0	0	8	297	191	146	31	40	30
N	5	0	29	1	0	4	270	207	113	29	44	25
O	4	4	57	1	1	8	190	113	88	13	28	21

Table 4.2 (cont'd)

Charact.	L_{ha}	L_{hs}	L_{hc}	N_{ha}	N_{hs}	N_{hc}	L_{va}	L_{vs}	L_{vt}	N_{va}	N_{vs}	N_{vt}
P	6	12	54	1	3	6	140	91	16	8	21	4
Q	4	4	68	1	1	9	206	121	117	17	30	26
R	0	0	51	0	0	6	195	102	73	14	24	16
S	8	8	90	2	2	14	114	32	59	14	8	13
T	0	0	44	0	0	4	108	4	4	5	1	1
U	0	0	34	0	0	4	201	137	101	10	32	24
V	0	0	22	0	0	3	204	127	86	29	28	20
W	8	4	35	2	1	5	189	71	50	24	17	12
X	0	9	43	0	2	8	269	153	72	40	30	15
Y	11	18	29	2	4	4	159	69	16	25	15	4
Z	0	0	85	0	0	5	86	134	0	14	28	0

The extended identification database in Table 4.2 showed that the 12 parameters identifications has more description for characters which allowed the system to have better discrimination between characters than the four parameter database of Table 4.1.

Due to a range of environments in which car images are acquired, then characters can be changed slightly from one plate to another. The system depends mainly on one group of identification to compare the unknown character, so in the case of non-ideal environments the system could produce incorrect recognition because of the close similarity between some identifications. Training the system with images produced in different environments such as illumination, cleanliness and clearness, will increase the dissimilarity between the identifications of the characters and improve the rate of successful recognition.

The training process was achieved by replacing the identification with an average value for the group of identifications. The extended character identification database matrix will then have an extra column (w) such as:

$$[w, L_{ha}, L_{hs}, L_{hc}, N_{ha}, N_{hs}, N_{hc}, L_{va}, L_{vs}, L_{vt}, N_{va}, N_{vs}, N_{vt}]$$

This element is not used in the recognition process, but rather it is only a weight (w) element, and will be the reference for the training process. With the existing database (Table 2), initially the value of the weight (w) is 1 for all characters, and then with any other identification (ID_o) for a character the system will average it with the database identification (ID_d) of the same character according to the weight value and produce a new identification (ID_n):

$$ID_n = w * (ID_d) + ID_o \quad (4.1)$$

The system increments the value of the weight of this character identification by one and the incremented weight with the new identification (ID_n) will replace the existing database row for this character.

The training process provides the system with car images with information about the registration number. The system executes a similar procedure to the recognition process, in order to separate the registration plate characters and produce their identification. Then the database will be trained for the characters presented by the information of the registration plate, and the training for each character will be processed according to the identification produced from the plate according to the equation 4.1.

4.3.6 Matching the Character Identification with the Database

The system recognized the registration plate character by measuring the error factor (E_{cd}) between the unknown character extended identification array and the database matrix rows without the weight element. Let the array of the unknown character be (C_u) where:

$$C_u = (L_{hau}, L_{hsu}, L_{hcu}, N_{hau}, N_{hsu}, N_{hcu}, L_{vau}, L_{vsu}, L_{vtu}, N_{vau}, N_{vsu}, N_{vtu})$$

and the database n th row which presents a certain character (n) is (D_n) where:

$$D_n = (L_{han}, L_{hsn}, L_{hcn}, N_{han}, N_{hsn}, N_{hcn}, L_{van}, L_{vsn}, L_{vtn}, N_{van}, N_{vsn}, N_{vtn})$$

The error factor between an unknown character and the n th row of the database (E_{cd}) was calculated as the sum of comparison array:

$$E_{cd} = \sum |(D_n - C_u)| / (|(D_n)^2 - (C_u)^2|)^{1/2}$$

The error factor between the unknown character and every row of the database will be calculated separately and the system will select the minimum error. If the minimum error was greater than a predetermined threshold then the character was not matched by any of the database characters and not recognized by the system. Otherwise, the minimum error corresponded to the character identification in the database.

CHAPTER 5

RESULTS AND INTERPRETATION

The automatic car registration plate recognition using the Hough transform system was processed in a number of steps such as location of the registration plate, the characters area extraction, the extraction of the individual characters within the plate area, and the plate characters recognition. The system used for the experimental test was designed so that when the system was applied to a vehicle image it paused after the execution of each step to show the image produced from this step and recorded the result. The system then proceeded on for subsequent steps until the completion of the registration plate recognition system execution. Then the system was applied to another image at the same sequence and so forth till the end of the test.

The imaging system was applied to fifty video images which were recorded for vehicles in different environment conditions, and the results of applying each step of the imaging system and the performance of the visual images produced were recorded. The results and the observation of performance were analyzed to produce a general interpretation of the performance of the project.

5.1 The Results

The results of the application of the automatic car registration by using the Hough transform system on the test plates are presented in Table 5.1. The first column of the table shows the car registration numbers, the next column includes how successful the registration plate was extracted (EXT. for car registration plates successfully extracted and Not EXT. for the plates that procedures failed to extract). Also this column shows in which extraction mode (Normal, Dark and Light) the plate area was extracted. The next column gave the results of the character area extraction (A , \tilde{A}) where A refers to correct extraction and \tilde{A} is for an incorrect extraction. The individual character extraction ratio C was given in the form ($C=a/b$) where b is the number of character per the registration plate and a is the correctly extracted characters. The plate recognition column presents the final result of applying the system

to the full images where the system produces its determination of the plate characters. The remaining column is the number of correctly recognized characters in each registration plate out of the correctly extracted characters from the plate. The comments column of the table includes the observations of the images produced by processing each step as well as the vehicle image. These comments were very useful in the analyses of the incorrect results.

Table 5.1
The Results of Applying the Imaging System to the Test Plates.

No	Plate Number	Plate extract.	Ch area extract.	Plate Recog.	Correct Reading	Comments
1	8CS.733	EXT, N	A,C= 7/7	8CS.733	7/7	
2	7HI.538	EXT, D	A,C= 7/7	74I.538	6/7	
3	7IE.131	EXT, D	A,C= 7/7	7IFJ131	5/7	Drawing in dot area
4	8CO.025	EXT, N	A,C= 7/7	8CO.025	7/7	
5	8IT.370	EXT, N	A,C= 7/7	8IT.370	6/7	
6	9FP.398	EXT, D	A,C= 6/7	9TP.39F	5/6	Ch. cut at right side
7	9JE.801	EXT, N	A,C= 7/7	9JE.801	7/7	
8	6NT.354	EXT, L	A,C= 7/7	6NT.3S4	6/7	
9	9HU.709	EXT, L	A,C= 7/7	9HU.709	7	
10	8ZR.260	EXT, N	A,C= 5/7	JZR.261	5/5	Ch. cut at both sides
11	9GJ.813	EXT, D	A,C= 7/7	6GJ.813	6/7	
12	8LZ.512	EXT, N	A,C= 7/7	8LZ.G12	6/7	
13	7EG.430	EXT, N	A,C= 7/7	N/A	N/A	Distorted image
14	DE.1524	EXT, N	A,C= 7/7	DE.1S24	6/7	
15	7HZ.551	EXT, D	A,C= 7/7	IHZ.CS1	4/7	
16	9JW.621	Not EXT.	N/A	N/A	N/A	Reflection on a white car
17	9LY.056	EXT, D	A,C= 7/7	8LY.D80	3/7	Distorted
18	9AK.931	EXT, N	A,C= 7/7	9AK.931	7/7	
19	9CW.956	EXT, N	A,C= 7/7	9CW.956	6/7	
20	7ES.866	EXT, D	A,C= 7/7	7E5.866	6/7	
21	7FA.273	EXT, N	A,C= 7/7	7EX.273	5/7	
22	8OY.896	EXT, D	A,C= 7/7	88Y.896	6/7	
23	9GW.245	EXT, D	A,C= 7/7	8XQ.245	4/7	
24	7KA.674	EXT, N	A	N/A	N/A	STRIPPED FRAME
25	7XE.702	EXT, D	A,C= 7/7	7XE.702	7	

Table 5.1 (cont'd)

No	Plate Number	Plate extract.	Ch area extract.	Plate Recog.	Correct Reading	Comments
26	9FW.295	Not EXT.	N/A	N/A	N/A	Yellow and black frame
27	8LZ.977	EXT, N	A,C= 7/7	8LZ.973	6/7	
28	8CO.025	EXT, D	A,C= 7/7	8CR.825	5/7	
29	9GO.869	EXT, N	A,C= 7/7	9S8.86P	4/7	
30	8BD.141	EXT, D	A,C= 7/7	89D.141	6/7	
31	7AT.755	EXT, D	A,C= 7/7	7AT.755	7/7	
32	6AM.170	Not EXT.	N/A	N/A	N/A	Yellow car
33	7DA.363	EXT, N	A,C= 6/7	3DA.39S	4/6	Ch. cut at left side
34	9BM.199	EXT, D	A,C= 7/7	9BMC199	6/7	Marks around the dot
35	8EU.807	EXT, N	A,C= 7/7	8JU.807	6/7	
36	8ZT.844	EXT, N	A,C= 7/7	8ZI.B44	5/7	
37	9PF.398	EXT, D	A,C= 6/7	6PF.39E	5/6	Ch. cut at right side
38	9JE.801	EXT, D	A,C= 7/7	9JL.801	6/7	
39	9DJ.995	EXT, D	A,C= 7/7	9DJ.365	5/7	
40	9KR.316	EXT, D	A,C= 6/7	9KR316	6/6	Small size dot
41	9GH.941	EXT, D	A,C= 6/7	8GH941	5/6	Small size dot
42	9HC.133	EXT, N	A,C= 6/7	GHC.1SL	4/6	Ch. cut at right side
43	9IG.946	EXT, N	A,C= 7/7	6IG.G46	5/7	
44	9KU.004	EXT, N	A,C= 7/7	9KU.004	6/7	
45	9LL.826	EXT, N	A,C= 7/7	9LL.8Y6	6/7	
46	9BN.326	EXT, N	A,C= 7/7	9BN.326	7/7	
47	9FE.669	EXT, N	A,C= 7/7	9FE.669	7/7	
48	9DB.532	EXT, N	A,C= 7/7	9DB.562	6/7	
49	9GH.941	EXT, D	A,C= 7/7	9GH.P41	6/7	
50	9MW.774	EXT, N	A,C= 7/7	8QW.77H	4/7	

5.1.1. Plate Area Extraction

According to Table 5.1 the results of the registration plate area detection was at the rate of 94%, and the plates that the system failed to extract successfully were for the following image cases:

- A yellow car: The system fail to extract the registration plates of yellow cars as the car body has the same colour features as the registration plate.
- A registration plate surrounded with a frame of yellow and black stripes: The extraction was not successful because the frame has a feature similar to the registration plate.
- A white car with the light reflection on the dust formulating yellow patches: The reflection made some parts of the car appear as a yellow colour which is the registration plate feature.

Even the extraction of the registration plate showed a reasonable success, but this result limited the use of this system for the non-yellow coloured cars.

Due to the different brightness conditions for every image (as was mentioned in Section 4.3.2) when the dimension features of a plate extracted in the normal mode did not match the expected dimension, then the system repeated the extraction in the dark and light modes. The results and chart of the extraction in the different modes as shown in Table 5.2 and Figure 5.1

Table 5.2
Plate Extraction Mode Result.

Extraction mode	Number of plates
Normal mode	25
Dark mode	20
Light mode	2

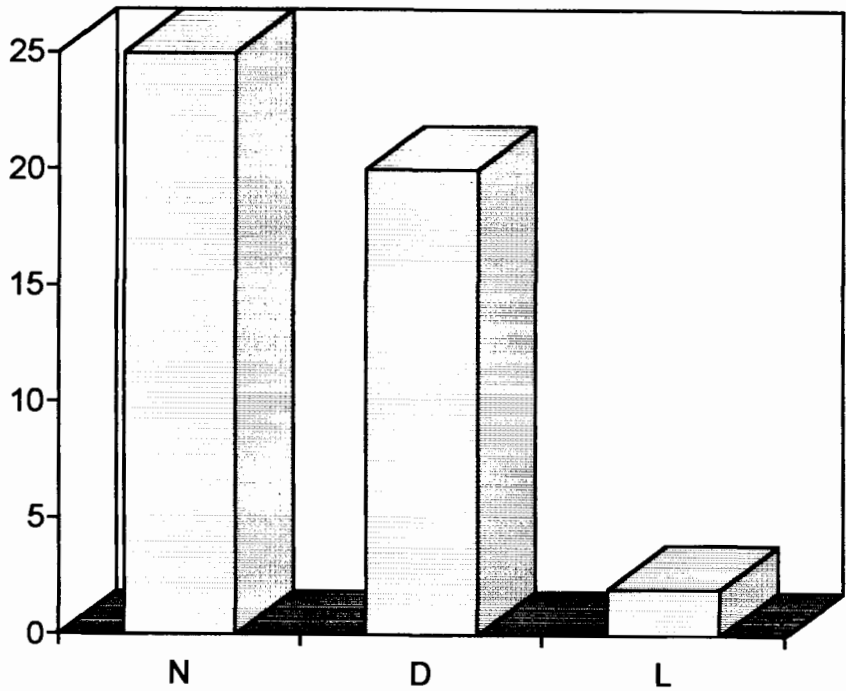


Figure 5.1: The distribution chart of the extraction modes

The Table 5.2 and the Figure 5.1 showed the number and the distribution of the plate extraction mode where most of the registration plate extortion was performed in the normal extraction and dark mode because most of the images were obtained in the day light.

5.1.2 Character Area and Characters Extraction

The characters area extraction algorithm was applied to a correctly extracted plate where the outcome was successful for all the tested plates with the exception of a single plate. The apparent reason was that the plate was surrounded with a black and white striped frame, and because of the chosen extraction method, the imaging system considered the frame as a part of the character area as it had similar features. However, the result of this extraction step was successful at the rate of 98% correctly extracted plate character areas out of the tested plates

The individual character extraction step was applied to the correctly extracted character area which extracted every character for recognition. The outcome of this process was determined and shown in Table 5.3:

Table 5.3
Results and Percentage of the Correctly Extracted Characters.

The process	Result
Correctly extracted registration plates and character area	46
Number of characters in each plate	7
Total number of characters (46 × 7)	322
Number of correctly extracted characters	314
The percentage of the correctly extracted characters	97.5%

The results showed that 2.5% of the individual characters were not correctly extracted, and there were several reasons for the incorrectly extracted characters:

- (a) Part of the characters in the side of the registration plate was covered by the surrounding frame, which hid a part of the edge of the character.
- (b) Small faint "dot's" less than the extraction threshold was not detected.

5.1.3 Registration Plate Recognition

Registration plate recognition is the final stage of applying the imaging system to the vehicle image which results in the automatic identification of the vehicle registration plate. The results of this stage of the processing were detailed in the plate recognition column of Table 5.1. The reviewing of these results were not only important as figures for the correct recognition but also it was important to evaluate the optical character recognition (OCR) system used in this study.

The final outcomes of the registration plate recognition were compared to the number of characters per plate and divided into the five groups designated a, b, c, d and e. The plates have the same number of correctly extracted characters per plate as shown in Table 5.4.

Table 5.4
The Correctly Recognized Characters Per Plate.

Plate group	Recognition per plate	Number of plates
(a)	Registration plates recognized 7/7	9
(b)	Registration plates recognized 6/7	19
(c)	Registration plates recognized 5/7	10
(d)	Registration plates recognized 4/7	5
(e)	Registration plates recognized 3/7	1

Note. plate number 13 in Table 1 was not considered in the results, as it was a totally distorted image.

The distribution of the recognition results of Table 5.4 is presented in the Figure 5.2. The distribution chart shows that the majority of extractions were around the 6/7 correctly extracted plates, which is an indication for the possibility of improving the results by modifying the system.

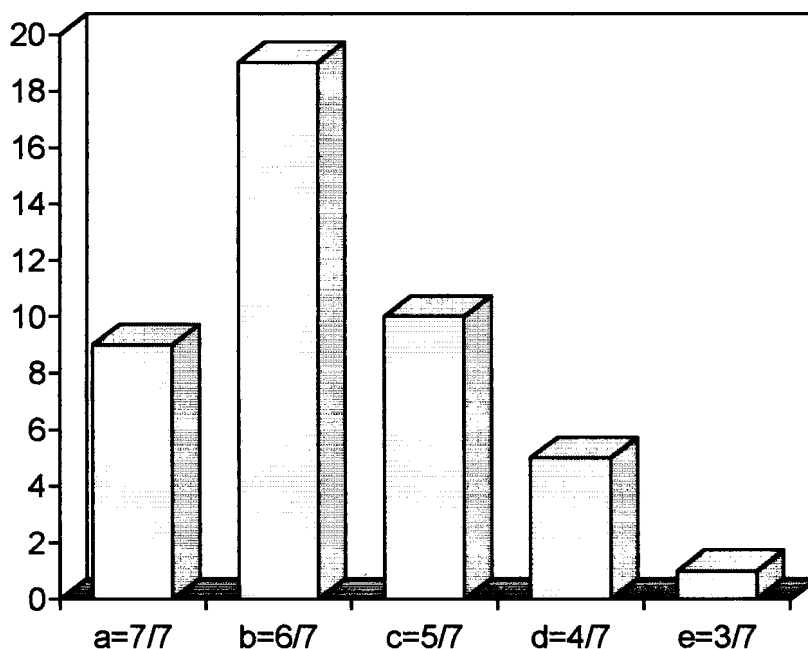


Figure 5.2: The distribution of the correctly recognized characters per plate

Table 5.5 includes the overall results of the recognition process, and it showed the number of the correctly recognized characters and compared them with the totally extracted characters and the total number of characters.

Table 5.5

The Correctly Recognized Characters Compared to the Correctly Extracted Characters and Total Number of Character in the Tested Plates.

Description	Results & Rates
The correctly recognized characters	254
The total number of the characters correctly extracted	307
The total number characters in the tested plates	350
The percentage of the correctly recognized characters	82.7%
The overall result of the process	72.5%

The Table 5.5 is another form of presentation for the correctly recognized characters which indicates the number of correctly recognized characters compared to the correctly extracted characters and the total number of characters in the extracted plates. It also includes the percentage rate of the correctly recognized characters compared to the correctly extracted characters and total number of characters. The Table 5.5 showed that the rate of correctly recognized characters was 82.7% of the correctly extracted characters, which showed that it is possible to recognize a registration plate character by comparing its identification features to the identifications database. The correctly extracted character rate included in Table 5.5 also showed that the Hough transform technique is a suitable tool to identify characters. Also the overall result of the registration plate recognition process was 72.5% which indicated that this processing system can perform the automatic car registration plate recognition process.

The characters, which were incorrectly recognized, are presented in Table 5.6 along with the incorrect implementation for each character and the percentage of the incorrect recognition for each character compared to the number of times they have been recognized.

Table 5.6
Recognition Statistics for the Mistaken Characters

The character	Mistake %	Incorrect implementation
0	18%	D, 8
2	10%	Y
3	15%	S, 2
4	10%	H
5	46%	S,G,C
6	7%	9
7	8%	I,3
8	8%	B
9	3%	8,6,P,G,3

Table 5.6 (cont'd)

The character	Mistake %	Incorrect implementation
A	18%	X
B	40%	8,9
E	33%	F,J,L
F	40%	T,E
G	28%	X,S
H	16%	4
M	33%	Q
S	50%	5
U	33%	H
W	20%	Q

Note. the results do not include the 100% correctly recognized characters and the Q, V characters which are rarely used on Western Australian registration plates.

The results in Table 5.6 include two types of incorrect recognition:

- (a) Incorrect recognition due to poor discrimination between some pairs of characters such as 5 and S, H and 4, 8 and B, E and F, and 9 and 6. This poor discrimination was because of the relative similarity between the identifications of each pair, thus a slight change in the character image of one of them could be recognized as the closest character.
- (b) Individual incorrect recognitions were mostly due to distortion in these characters images which produced different identifications for these characters.

Type (a) errors of incorrect recognition can be classified as a system capability problem and the type (b) errors were a result of image capture problem, and the evaluation of these results will be discussed in Section 5.2.

5.1.4 The Execution Time

The execution time for the processing of the registration plate varied from plate to plate due to the alternative processing systems used according to the plate environment. The extraction of the registration plates in the normal mode required shorter time than the plates extracted in the dark or the light modes. The tilted plates also required longer execution time for normalizing the plate before the image extraction.

The Table 5.7 shows the time required for the extraction of a registration plate in the different extraction modes and the time required to recognize the horizontal and tilted plates.

Table 5.7
The Execution Time for Extraction and Recognition Process

The plate image process	Processing time
Plate extraction in normal mode	1.5 Seconds
Plate extraction in dark mode	2.5 Seconds
Plate extraction in light mode	4.0 Seconds
Recognition of a straight plate	4.0 Seconds
Recognition of a tilted plate	6.0 Seconds

These execution times shown in Table 5.7 have considerably long duration where the range of total processing time was between 5.5 seconds minimum and a maximum of 10.0 seconds. The reason for the long processing duration was that the speed of processing was not the main objective of the study, so that the Matlab programming language was used for construction of the system software which is suitable for the image processing experimental but not particularly fast. The processing speed of the system can be considerably improved with specialized programs in a processing chip.

5.2 Analyses of the Results

The results of applying the imaging system to the registration plates can be divided into three major topics: extraction, character recognition and the execution time of the image processing techniques. The results of these major topics will be evaluated and analyzed in this section.

5.2.1 Analyses of the Extraction Process

The extraction process is a combination of three processes: registration plate extraction, characters area extraction and individual character extraction. The overall extraction result was 89.7% success with 10.3% errors rate. The error can be divided into:

- (a) 5.7% errors due to using plate frame covering part of the plate or a frame which has features similar to plate or plate characters features.
- (b) 4% errors due to the colour of the vehicle or for a colour produced by the reflection.
- (c) 0.6% errors due to other reasons such as the faint small 'dot'.

These errors are related to registration plate structure and the limitation of plate extraction technique.

5.2.2 Analyses of Character Recognition process

Testing the character recognition technique that used the Hough transform to identify the characters was the main aim of this project, and to show that it is possible to recognize a character by comparing its identification to an identification database. The study aimed to demonstrate that the Hough transform is a suitable technique to produce the character identification that can be used to recognize the characters. The result of the recognition process showed that it is possible to use this optical character recognition (OCR) system in registration plate recognition at least with an 82.7% success.

The analyses of the experimental results presented in Table 5.1 and the registration plate recognition results (Section 5.1.3) showed that the incorrect recognition were due to the following reasons:

- (a) It was observed that the clear sharp edged images were recognized better than the distorted images, especially the images that have spike distortion around the edge. The main reason for this distortion was the unsteady video image which was captured and this spike distortion become worse when the image was rotated.
- (b) The dirt on the plate could cause an incorrect recognition. When the dirt was located between two characters it caused unsuccessful extraction. Also if it covered all or part of a character, then the identification array produced will be different to the identification array for this character, an so the character will be incorrectly recognized.
- (c) The system doesn't have a superior discrimination between some character pairs such as 5 and S, H and 4, 8 and B, E and F, and 9 and 6. The poor discrimination is due to the relative similarity between the identification arrays of these pairs, thus any slight change in a character image of one of them could be recognized as the nearest identification of a character. This type of incorrect recognition is due to a limitation of the identification system associated with the image distortion.

While the first and the second reasons for incorrect recognition were due to the image clarity, the third explanation was considered a result of a limitation on the system capability. It is clear that recognition of a quality character image will give better results. Therefore a better image capture and character image enhancement will improve the results of applying this system to the car registration plates.

5.2.3 Evaluation of Execution Time

These execution times for processing the project stages presented in Section 5.1.4 showed that a considerably long execution time was required for the extraction and recognition process. As it was mentioned in Section 5.1.4 that the processing time was not the main object of the study therefore it was not considered in the construction of the system procedures. Thus implementing

the system in specialized software or in a hardware chip will speed processing of both the extraction and recognition and improve the execution time.

5.3 Interpretation and Outcomes

The experiment results and the analyses of these results showed that this project fulfilled the aim of the study. It proved that it is possible to use the Hough transform technique in car registration recognition, and also it was tested for the Australian plate for the automatic recognition system. This Section will consider interpretation of the experiment results and also will include analyses of the Hough transform outcomes discussed in Section 4.3.1.

5.3.1 Interpretation of the Results

Although applying the study technique did not show significance in the recognition results, the outcomes of the experimental test indicated the possibility of applying the theoretical approach of character recognition by comparing an unknown character identification to identification database. Also it showed that the Hough transform is a satisfactory tool for character identification and recognition.

The study showed that the automatic car registration plate recognition system is applicable for the Australian registration plates. The implementation showed that there were some incorrect extractions and incorrect recognition's was because of few problems related to the Australian plate application. The main difficulty came from the frames used by some vehicles (this frame is not part of the plate but used as a sort of decoration), and this frame sometimes covered part of the plate which caused wrong extraction or incorrect recognition. Also some frames include stripes of contrast colours which have the same features of the plate, which caused wrong characters extraction. Also the study showed that the size of the "dot" point could produce an extraction problem especially for the faint characters or bright plate images.

This study could be considered as the foundation for further research by both improving this car registration plate recognition system and implementing the Hough transform recognition method in other applications.

5.3.2 Outcomes of the Hough Transform

Applying the Hough transform on the character edge horizontal lines showed that there were no solution points in the T quadrant, while the Hough transform of the vertical lines formed no solution points in the C quadrant (Section 4.3.1). The disappearance of the solution points in these quadrants can be accounted as follows:

The horizontal transform in the T-quadrant: The group of horizontal lines shown in Figure 5.3 are for image space lines that have negative slope to the y-axis (between 0° , -45° to the horizontal) and situated in the positive part of the image space. None of these lines will have the chance to intersect with the negative part of the y-axis. Therefore there will never be any line of this image space group with $(-c, -m)$, which could have a solution point in the T-quadrant.

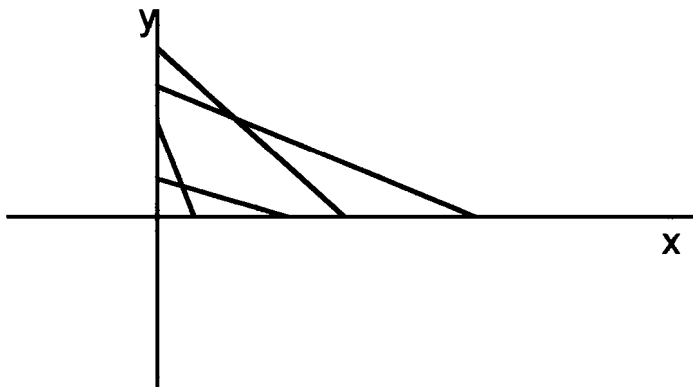


Figure 5.3. A group of lines in the positive image space quadrant.

The vertical transform in the C-quadrant: The Figure 5.4 shows a group of vertical lines with 90° positive rotation for the image space. In Figure 5.4 the lines have slope angles between 0° and 45° to the horizontal, considering that the axes have been rotated, then these lines have absolute angle slopes between 90° and 135° to the x-axis which is a negative slope.

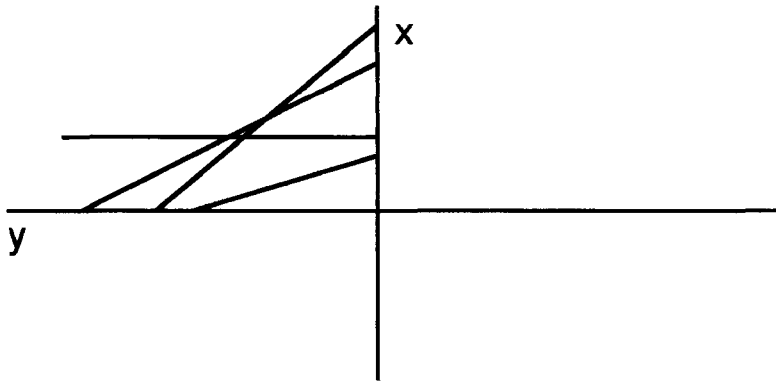


Figure 5.4. A group of vertical lines in the rotated axis image space.

The lines of the rotated image that which have negative slope did not have the chance to intersect with negative part of the x-axis. Therefore it is not expected to have a solution in the negative slope and negative intercept parameter space quadrant. These findings associated to reduce the number of parameters of extended character identification to 12 instead of 16, which speeded the identification process.

CHAPTER 6

CONCLUSION

This chapter concludes the study and it contains a summary of the research methodology and the experimental results. The chapter also contains limitations of the study and a discussion of the outcomes of the investigation as well as the implementation of the research and recommendations for further research based upon the techniques used in this study.

6.1 Overview of the Study

The aim of this study was to explore the potential of using the Hough transform in car registration plate recognition as well as to examine the possibility of using an automatic car registration plate recognition system for Australian vehicle registration plates.

To achieve this aim an operating system for a car registration plate recognition system was constructed. The system methodology can be summarized as the following:

Registration plate area detection: The group of car images used in this project had a yellow background with black characters, so a colour image processing method was used to segment the registration plate of the car image and extract the area that has the plate colour features. Although the current system has been configured to detect only yellow background it could, equally well detect other specified colours of backgrounds.

Normalizing the plate: It was shown that the character identification would change with tilting and with varying sizes of the plate. Therefore, it was important to normalize the plate before segmentation and identification. This was achieved by detecting the tilt angle and changing the size of the plate. Applying the Hough transform to the registration plate horizontal edges and monitoring the parameter space slope distribution, the peak of this distribution indicated the tilt angle of the registration plate. If the tilt angle was not zero

then the system will tilt the plate image with an angle equal and opposite to the plate tilt. The size variation was adjusted for each individual character after the extraction process by measuring the character height and then resized the character image to the ratio between the standard height and the character height.

Characters extraction: The character extraction process was performed by extracting all the plate characters from the border, by following the boundaries of the colour concentration in the plate. Then the system followed the boundaries between characters to extract the individual characters.

Character identification: In the automatic registration plate identification system the characters were identified by an array including information about the number and the length of the character edge lines. Producing a character identification array was performed in following steps:

- (a) Application of an edge detection algorithm to the character image to detect the character edges.
- (b) Application of the Hough transform algorithm to the character edge image and then a search of the parameter space produced from the transform to calculate the parameters of the identification array.

Construction of the database: The database was prepared from the identification of the registration plate characters templates which have been manually separated for the digits 0 to 9, the letters A to Z, and the "dot" point which is used in the Australian registration plate. The edge detection algorithm was applied to these templates, and with the use of the Hough transform technique the system produced the identification arrays for the database characters. The database was constructed in the form of matrix including the characters identification arrays.

Character recognition: The system recognized a character extracted from the registration plate by comparing the identification array of this character to the database matrix. The system measured the distance between the unknown character identification and every identification array within the database. The database character that had the heights match the unknown character was considered to be the solution.

This application was implemented on video recorded car images and this implementation produced the following major results.

The success rate for the registration plate extraction was 94%. The plates which the system failed to successfully extract were for the case of a yellow car, a registration plate surrounded with a frame of yellow and black stripes, and a white car with the light reflection on the dust forming yellow patches.

The rate of correctly extracted characters area was 98% of the tested images, and percentage of the correctly extracted characters was 97.5%. The reason for the incorrect extraction for both the characters area and the individual characters was mainly due to the surrounding frame attached to the registration plate in some vehicles.

The percentage rate of the correctly recognized characters was 82.7% of the correctly extracted characters. The reason for the unsuccessful recognition was due to:

- The method used for recording the car images was not fast enough to eliminate the distortion on the image. This distortion was produced from the relative movement between the camera and the vehicle.
- The dirt on the plate.
- The limitation of the system, where the system does not have sufficient discrimination between some characters pairs.

This study adopted new techniques in the car registration plate recognition including:

- (a) An identification matching method in optical character recognition (OCR).
- (b) Application of the Hough transform to produce the characters identifications array.
- (c) Measurement of the registration plate tilt angle by using the Hough transform.

6.2 Limitation of the Implementation

The results of the experiment showed that the system in its present condition is not perfectly reliable because of small unsuccessful recognition rate. The results showed that this new technique in OCR is suitable, and better precision can be obtained after modifying the procedures and avoiding the problems that caused the unsuccessful results. A discussion of the limitations of the application and the reasons for these limitations are:

The recognition results: The rate of character recognition for the correctly extracted characters was 82.7%, which made the system not highly reliable in its present form. The analysis of the results showed that the unsuccessful recognition was due to the following main factors:

- (a) The distortion in the image due to the relative movement between the video camera and the vehicle produced distortion in the character's image and this distortion produced different identifications for the characters. The result will be improved when the image distortion is reduced by using a higher speed digital camera and applying image enhancing techniques for the registration plates before the identification process. This modification will eliminate the image distortion.
- (b) The limitation of the identification technique used in this study caused a poor discrimination function between some character pairs such as S and 5, H and 4, 8 and B, E and F, and also 9 and 6. The discrimination may be improved when the character identification database is modified by using a well-trained neural network system to obtain a better discrimination function.

The Australian registration plate: Even the experiment was conducted on the yellow background Western Australian registration plates, the analyses of the results showed that the several features related to the Australian registration plate caused some extraction and recognition problems:

- (a) The frame, which is not part of the plate but used by some vehicles as a decoration for the plate, caused major problems in the characters recognition as it may hide a part of the side character of the registration plate. Also the results showed that some of these frames had features

similar to the registration plate features, such as the frames that had contrasting colour stripes (black and white stripes), which caused an incorrect plate and characters area extraction.

- (b) The size of the 'dot' and the distance between it and the neighboring characters to it are relatively small, so that the system could not detect the extraction of the 'dot'.

Therefore it is recommended to the licensing authority to have regulation for these frames. This regulation should either not allow fitting frames around the registration plates or to regulate the size and colour of these frames so that it should be larger than the plate size, and its colour should be suitable for the extraction technique. Also it is recommended to increase the size of the 'dot'.

The registration plate extraction method: The system adopted a colour extraction technique for registration plate extraction. The results showed that this technique failed to extract the registration plate for the vehicles that have the same colour as the registration plate. Thus the registration plate extraction method will be limited to the cars that have colours different to the registration plate.

6.3 Outcome and Conclusion

Although the result for the automatic car registration plate recognition by using the Hough transform system was reasonably successful, there were still aspects of the project which can be improved. This section will discuss outcomes of the project and conclude the significance of these outcomes.

The study showed that the plate characters could be recognized by comparing a character identification array to the identifications database. Also the extended characters identification array produced by using the Hough transform showed that it was a reliable tool to produce identification for a character. This identification process was applied to characters recognition and the technique was able to successfully recognize 82.7% of the tested characters.

The car registration plate recognition system described in the methodology (Section 4.3) and summarized in Section 6.1 is a functioning system for car

registration plate recognition which was able to apply the Hough transform technique with 72.5% overall characters recognition.

The pilot study of the project indicated that the Hough transform technique was not applicable for the different sizes of characters and the registration plates with different tilt angles. Therefore, these variations were considered in the development of the project methodology where the characters were resized to a standard format and fitted in a standard border before the identification process. Also the procedures were constructed so that the registration plate angle of tilt was measured after extracting it from the car image by applying another Hough transform algorithm to measure the registration plate tilt angle. The system normalized the plate and the technique was successfully performed during the project experiment.

During the preparation of the characters extended identification database it was noticed that there were no solution points for the vertical transform in the C-quadrant and for the horizontal transform in the T-quadrant. The reason of this phenomenon was because the character image was situated in the positive part of the image space. Therefore the lines that have a negative slope will never have a chance to intersect with the negative part of the y-axis. This finding reduced the reduced the size of the character identification array and reduced the process time as a result of not scanning these quadrants.

6.4 Implementation of the Study and Recommendation for Further Research

A new recognition technique was introduced in this study by applying the Hough transform to identify an object and then it will be recognized by matching the unknown object identification with a group of known expected objects identifications. This technique showed that it could be implemented in car registration plate characters recognition as well as it can be applicable in some other automatic optical character recognition.

Although the study showed the possibility of using the project concept in car registration plate recognition, the evaluation of the result recommended number of modifications to the system. These modifications can be addressed in further research to modify the system to improve the extraction and

recognition rates. The following are the areas where the system needs to be improved:

- Producing registration plate images with minimal distortion, by selecting an image capture method which is not affected by the relative movement between the vehicle and the camera.
- A study to improve the registration plate recognition by applying better training and recognition method such as using a neural network for characters recognition.
- Testing the possibility of using other types of plate character identification parameters according to the information available from the parameter space matrix produced by applying the Hough transform to the character image.

Also, this automatic recognition technique can be applied in the following application:

- An automatic text reading by applying the system as an optical character recognition.
- The automatic monitoring of some manufactured products that have a shape composed of straight lines. The system can be used to recognize the correct product and reject the products that not recognized.
- Firearm fingerprints on the cartridge case identification. The Hough transform technique can be used to produce an identification array for the firearm fingerprint, which may help in the recognition of the cartridge case.

The principle of recognizing an object by comparing its identification profile, has many applications in the automatic recognition of simple shapes where their edges are composed of connected lines. There are many other areas for research where the concept of identification and recognition can be applied.

REFERENCES

- Block, H. D. (1962). The preceptron: A model for brain functioning. Reviews of Modern Physics. 34, 123-135.
- Brice, C. R. and Fennema, C. L. (1970). Scene Analysis using regions. Artificial Intelligence. 1, 205-226.
- Carling, A. (1992). Introducing Neural Networks. Wilmslow, UK: Sigma Press.
- Comelli, P., Ferragina, P., Granieri, M. N., and Stabli, F. (1995) Optical recognition of motor vehicle license plate. IEEE Transaction on Vehicular Technology. 44(4), 700-709.
- Doyle, W. (1962) Operation useful for similarity-invariant pattern recognition. J.ACM. 9, 259-267.
- Fahmy, M. M. (1994) Automatic number-plate recognition: neural network approach. Vehicle Navigation and Information Systems Conference Proceeding, (pp. 99-101).
- Frei, W. and Chen, C. C. (1977) Fast boundary detection: A generalization and new algorithm. IEEE Transactions on Computers. C-26, 556-566.
- Fu, K. S. and Mui, J. K. (1981) A survey if image segmentation. Pattern Recognition. 13(1), 3-16.
- Giardina, C. R. and Dougherty, E. R. (1988) Morphological Methods in Image and Signal Processing. Prentice Hall.
- Gonzalez, R. C. and Wintz, P. (1987) Digital Image Processing. (2nd edition) Addison-Wesley Publishing Company.

- Guil, N., Villaba, J., and Zabata, E. L. (1995) A Fast Hough transform for Segment Detection. IEEE. Transaction on Image Processing. 4(11), 1541- 1548.
- Haralick, R. M. and Shpiro, L. G. (1992) Computer and Robot Vision. Addison-Wesley Publishing Company.
- Harrison, B. A. and Jupp, D. L. B. (1990) Introduction to Image Processing. Australia: CSIRO.
- Horowitz, M. (1957. Efficient use of a picture correlator. J. Opt. Soc. Am. 47, 327.
- Hough, P. V. C. (1962) A Method and Means for Recognizing Complex Pattern Digital Image Processing. (2nd edition) (Gonzalez, R. C. and Wintz, P.) Addison-Wesley Publishing Company.
- Jain, R. (1981). Dynamic scene analysis using pixel-based processing. Computer. 14(8), 12-18.
- Jain, R. (1983). Segmentation of frame sequences obtained by moving observer. Report gmr-4247, General Motors Research Laboratories, Warren, Mich.
- Lee, E. R., Kim, P. K. and Kim, H. J. (1994) Automatic recognition of a car license plate using color image processing. Proceeding. International Conference on Image Processing (vol. 2, pp. 301-5).
- Lotufo, R., Morgan, A. D., and Johnson, A. S. (1990) Automatic number-plate recognition. IEEE Colloquium Image Analysis for Transport Applications. 035, 671-676.
- Muerle, J. L. and Allen, D. C. (1968) Experimental evaluation of techniques for automatic segmentation of objects in a complex scene. In pictorial pattern recognition. (G. C. Cheng *et al.* eds.) Washington: Thompson book Co.

- Narasimham, R. and Fornago, J. P. (1963) Some further experiments in the parallel processing of picture. IEEE trans. Elec. Computers. EC-12, 748-750.
- Nilson, J. N. (1965). Learning machines. NY: McGraw Hill.
- Poon, J. C. H., Ghaiali, M., G. M. T. and Sheung, L. M. (1995) A Robust Vision System for Vehicle Registration plate recognition using gray scale morphology Proceeding of the IEEE International Symposium on International Electronics (vol. 1, pp. 394-9).
- Rajala, S. A., Riddle, A. N. and Snyder, W. E. (1983). Application of the one dimensional Fourier transform for tracking moving object in noisy environments. Compute. Vis. Graph. Image Proc. 21, 280-293.
- Rosenblatt, F. (1962). Principles of neurodynamics. Washington: Spartan Books.
- Rosenfeld, A., *et al.* (1965) Automatic Cloud Interpretation. Photogramer Eng. 31, 991-1002.
- Sobel, I. E. (1970). Camera model and machine perception. Ph. D. Thesis, Electrical Engineering Department, (Stanford University, Stanford, CA).
- Sze, T. W. and Yang, Y. H. (1981). A simple contour matching algorithm. IEEE Trans. pattern anal. Match. Intell. PAMI-3 (6), 676-678.
- Tindall, D. W. (1995). Application of neural network techniques to automatic license plate recognition. European Convention on Security and Detection (pp. 81-85). Conference publication No. 408, IEE.
- Tindall, D. W. (1997). Deployment of automatic license plate recognition systems in multinational environments. European Convention on Security and Detection (pp. 42-46). Conference publication No. 437, IEE.
- Tou, J. T. and Gonzalez, R. C. (1974). Pattern Recognition. Addison-Wesley, Reading, Mass.

Vuillemin, J. E. (1994). Fast linear Hough transform. Proceeding. The international conference on application specific frequency (p. 1-9).

Zucker, S. W. (1976). Region growing: Childhood and adolescence. Computer Graphics Image Processor. 5, 382-399.

APPENDIX A

**Paper Presented at the IEEE 31st Annual International
Carnahan Conference on Security Technology
on
October 15-17, 1997.**

**by
Shokri Gendy, Clifton L Smith and Stefan Lachowicz**

Appendix A: page 98 to 109

Automatic Car Registration Plate Recognition Using Fast Hough Transform

**Shokri Gendy, Clifton L. Smith, and Stefan Lachowicz
School of Engineering
Edith Cowan University, Perth, Western Australia**

**Reprinted from
31ST ANNUAL 1997 INTERNATIONAL CAMAHAN CONFERENCE ON SECURITY TECHNOLOGY
October 15 - 17, 1997**

Automatic Car Registration Plate Recognition Using Fast Hough Transform

Shokri Gendy, Clifton L. Smith, and Stefan Lachowicz
School of Engineering
Edith Cowan University, Perth, Western Australia

Abstract: The development of automatic car registration plate recognition will provide greater efficiency for vehicle monitoring in automatic zone access control. Plate recognition will avoid the need to equip vehicles with special RF tags, since all vehicles possess a unique registration number plate. Also the proposed recognition system can be used in conjunction with a tag system for higher security.

There are a number of techniques which have been used for car registration plate characters recognition. These systems include BAM (Bi-directional Associative Memories) neural network character recognition and pattern matching of characters as two character recognition techniques which will be discussed in this paper.

The object of this paper is to explore the potential of using Fast Hough Transform (FHT) in vehicle registration plate recognition. Image processing techniques have been used to extract plate characters, then FHT algorithm is applied to every character in the image for recognition and identification. The FHT used in the paper is an efficient, fast and simple algorithm to identify characters, without requiring a relatively large memory.

INTRODUCTION

Law enforcement agencies have traditionally identified vehicles its features such as colour, shape and model of vehicle, or alternatively by the registration plate which is a unique identification for each car. In order to automate the recognition of vehicle registration plates, imaging systems have been developed to perform this task. As a result, many studies on automatic plate recognition have occurred over the last decade. The ongoing development of the automatic car registration plate recognition system will have an important role in future security, traffic control and vehicle identification systems.

The automatic identification of vehicles has been in considerable demand specially with the increase in the vehicle based offences. It can also play an important role in security zone access control and automatic toll road collection. Many systems have been introduced since the last decade [1, 2, 3, 4], with these studies indicating the possibility of automatic registration plate recognition systems for the plates of a variety of nations (for example, British, Korean, and Italian), but none were applied to Australian registration plates.

This study will explore the efficiency of a new technique of character recognition by the optical character recognition

(OCR) for car registration plates. Unlike other OCR systems where the full image is compared to a full image database, this proposed system recognises the characters by comparing its identification features or label to a characters identification database. Thus because character identification in this study requires less information, then the recognition will be faster and the database memory will be reduced.

PLATE IDENTIFICATION SYSTEMS

This investigation will use the Hough Transform to provide the character identification for registration plate recognition. So current image processing techniques will be described for previous research in car registration plate recognition systems and compared to process offered by the Hough Transform.

Image Processing

Image processing techniques have been reviewed by many authors such as Gonzalez and Wintz [5], Haralick and Shapiro [6], and Harrison and Jupp [7]. While the general image processing literature treats many areas in image processing, the following are the areas that have direct relation to this project:

Edge Detection: The edge in an image is the reasonably gradual or sudden change from dark to light or from light to dark of pixel intensity. The most common ways to extract the edges is by filtering the image with a suitable mask to calculate the gradient image of the edges. Sobel [8] developed a filter known as the Sobel operator which is composed of two 3 x 3 masks (Figure 1):

-1	-2	-1	-1	0	1
0	0	0	-2	0	2
1	2	1	-1	0	1

Figure 1: Sobel edge detector masks.

When the first mask is applied to an image it will detect the edge lines around the horizontal that have slopes between 1, -1, with the second mask detecting the remainder of the edge lines. The Sobel operator is more suitable for linear edge detection, while Frei and Chen [9] used a set of nine orthogonal masks that can be used as a general edge detector.

Image Segmentation: Image segmentation is the process of dividing the image into some constituent parts, so that the

processing can extract any part of the image for further processing. The segmentation is usually based on discontinuity and similarity of the gray level within the image.

Thresholding: One of the earliest techniques for image segmentation was thresholding which was based on the gray level distribution within the image as it is usually composed of gray level bands. The segmentation is performed by splitting out the area that has same gray level band from the remainder of the image.

Region-oriented segmentation: This technique is based on direct segmentation by dividing the image into smaller parts and assembling the neighbourhood areas that have the same features. The region-oriented segmentation technique has been reviewed by and Gonzalez and Wintz [5].

Motion-based segmentation: Unlike the other segmenting techniques which process a single frame image, this system analyses a series of time sequence frames captured by a fixed camera. By comparing these frames the system can segment the part of the image that has changed its position. There are two methods of segmentation applying a spatial technique and a frequency domain technique. The spatial technique described by Jain [10, 11], where the technique calculates the difference between two images on a pixel by pixel basis in both the x and y directions. If the change in any of the pixels was greater than a predetermined threshold, then the system segments the area that has changed. The frequency domain technique is another motion-based technique developed by Rajala, Riddle and Snyder [12]. In this method the system detects the motion via the frequency change in Fourier Transform of two consecutive images.

Image Recognition: In order to recognise an image, it is first required to extract its features for comparison. Features could be labelled or described, and unknown features or descriptions can be compared to known features for identification. Matching techniques will provide full image recognition using methods such as:

Distance measuring: Tou and Gonzalez [13] compared the description of a known image and the description of an unknown image, by measuring the distance between the two description vectors:

$$D(x_1, x_2) = \|x_1 - x_2\| \\ = \sqrt{(x_1 - x_2)'(x_1 - x_2)}$$

The technique measures the distances between the unknown vector and a group of known vectors, where the best match is the shortest distance.

Correlation: This is an efficient technique for image recognition which was developed by Horowitz [14]. This method measures the correlation coefficient between a number of known images with the same size unknown images or parts of an image with the highest correlation coefficient between the images producing the best match.

Neural network: The neural network is a type of processing in memory where data are not stored in a particular place, but rather in different neurons that are connected to each other. This system has the ability for self learning in a method called associate learning, where the neural network learns to produce a pattern of activation in a set of units whenever a certain pattern of activation is present to another set. The relation between patterns is called pattern association and the pattern associator is the system used to create the association between these patterns in different subsets. Unlike conventional memory processing where the information is stored in a physical location as a block of data, in the associative memory the data are spread in connected neurons.

The neural network for image recognition was pioneered by the work of Rosenblatt [15] and Nilson [16], where the network is trained to recognise the different possible patterns of a certain image. This training will produce a connection weight, which when presented to the trained network will produce a related output.

Registration Plate Recognition

Car registration plate character recognition have been conducted by Lotufo, Morgan and Johanson [1], Fahmey [2], Lee, Kim and Kim [3] and Comelli, Ferragina, Granieri and Stabli [4] using a variety of character recognition techniques. The automatic registration plate recognition procedure is performed by the following steps:

1. **Location of the registration plate:** When the vehicle is in range of the video camera the vehicle triggers an inductive loop detector so that the camera captures an image of the front of the vehicle. The digital image is stored in memory ready for image processing. A segmenting algorithm on the full image will be used for segmenting the car image, and the segmented part that matches the registration plate features will be extracted for optical character recognition.
2. **Normalising of the registration plate area:** When the registration plate has been located, it could be in a tilted orientation and/or not of the standard size. The system will measure the tilt slope and the heights of the characters and with an appropriate technique apply a correction to normalise the image.
3. **Character feature extraction :** Another segmentation is required to separate each character in the registration plate image. This is achieved by segmentation being applied to the normalised registration plate area in order to segment the characters from the plate background.
4. **Characters identification:** The identification of characters is only necessary for the systems that use identification matching techniques for image recognition. In this step, the system produces a unique identification for each of the characters.
5. **Character recognition:** The full image or the identification of the extracted characters will be compared to the database for matching by the highest correlation.

The registration plate recognition procedure is a crucial stage for the identification of the characters by matching techniques.

Registration plate recognition using B.A.M. neural network: Bi-directional associative memories (B.A.M.) are a neural network-based system based on a two layer feed back neural network (Figure 1) to encode patterns of pairs (A_i, B_i) . The encoding or learning in B.A.M. is carried out by modifying the weights between the neurons when connections are formed.

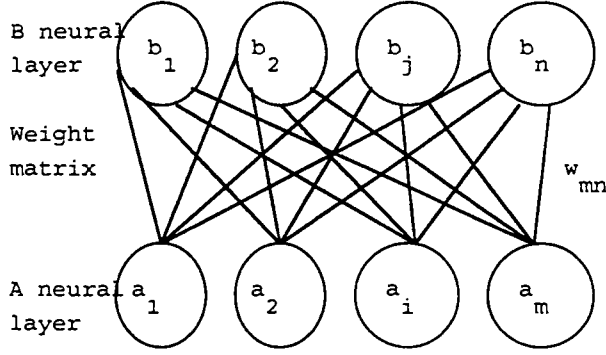


Figure 2: Bi-directional associative memories (B A M)

The two neuron layers are totally connected to each other but are not connected to the neurons within the same field. Every neuron a_i is connected to each neuron b_j by "snapses" which form the weight matrix, and the connection pattern between the neurons is the weight of the connection. The Figure 2 shows that the network has two fields A, B , where the field A of m neurons is:

$$F_A = \{ a_1, a_2, a_3, \dots, a_m \}$$

and field B of n neurons is:

$$F_B = \{ b_1, b_2, b_3, \dots, b_n \}$$

There are m neurons in F_A and n neurons in F_B , where every neuron is a simple nonlinear function that transforms the sum of the weighted input signal to an output signal, where the simplest form of an output is the binary (1 or 0). The neurons turn on or off according to the input and the value of the threshold. For example, when a threshold equals 0, if the input to the neuron was positive then the output will be 1; and the same with the negative input, which outputs 0, with the zero input, then the output will remain unchanged.

The neurons of the two arrays of field A and field B are in -1, 1. B.A.M. learned the association (A_i, B_i) by summing the correlation matrices, so that this association can be stored and recalled.

The weight between the two fields F_A and F_B which includes the connection information, is contained by the $m \times n$ matrix M . Stable B.A.M. is produced by different matrices M , where the network encodes a particular set of associations $\{(A_1, B_1), (A_2, B_2), \dots, (A_p, B_p)\}$ by summing the dipole correlation

matrices. In the learning process the binary pair (A_i, B_i) will be replaced by dipolar pair (X_i, Y_i) , where they are binary matrices using -1's instead of 0's. Every dipolar pair (X_i, Y_i) is converted to a bipolar correlation matrix $(X_i^T Y_i)$ (where X_i^T is the matrix transpose of matrix X_i). By adding the correlation matrices the mapping matrix can be obtained as:

$$M = X_1^T Y_1 + X_2^T Y_2 + \dots + X_p^T Y_p$$

After the B.A.M. has been trained with a number of pattern pairs (A_i, B_i) , it produces the mapping matrix M . This matrix M is able to recall B_i every time that A_i presents, or recall A_i when B_i presents. Also B_i will be recalled whenever something close to A_i is present. This operation makes it possible to use B.A.M. in the recognition of the characters within the registration plate.

Fahmy [2] used this concept in registration plate recognition where actual character patterns were extracted from the registration plates in 16×16 pixel format, where the value of every pixel will be either 1 (for black) or 0 (for white). The B.A.M. system is trained by characters extracted from actual registration plates and developed an output 6×6 matrix which is unique for every character. When a character pattern is presented to the system, it will produce an output matrix which will match one of the characters. The character pattern for the letters A to Z and numbers 0 to 9 are stored in multiple matrices each together with their association (desired output).

Registration plate recognition by using cross correlation pattern matching: The registration plate recognition process using cross correlation pattern matching was proposed by Comelli et al. [4]. In this system the database is a group of prototypes for all letters and digits in a template in a reasonable gray level and in a standard size.

After extracting the registration plate from the whole image, it was normalised and scaled to the standard size of the plate. Considering that characters within the registration plate are uniform (usually having the same number of characters with these characters located at regular fields in the plate), then the area of every character is scanned separately and recognised without the need for segmenting the plate into separate characters.

Registration plate normalisation: The recognition technique requires the registration plate characters to be a constant size and without any tilt. These conditions are achieved by the plate normalising process which is performed in two stages, by estimating the character size and evaluating the registration plate tilt, and then normalising the plate.

The method used to estimate the tilt angle and character height is performed by detecting some features for the plate. These features are the local minima points and local maxima points for the input image $f(x, y)$, where the local minima points satisfy the following condition:

$$\begin{aligned} f(x-2, y) &> f(x-1, y) > f(x, y) \\ f(x-2, y) &> f(x-1, y) > f(x, y) \end{aligned}$$

and local maxima points satisfy the following conditions

$$\begin{aligned} f(x-2, y) &\cdot f(x-1, y) \cdot f(x, y) \\ f(x+2, y) &\cdot f(x+1, y) \cdot f(x, y) \end{aligned}$$

These feature points which were extracted along the rows of the image are normally located at the character body and between the characters. The tilt angle can be determined by tilting the registration plate around its centre using suitable tilt angles between $(-\alpha_m, +\alpha_m)$ and then measuring the spreading of the characters features for every tilt position. From the spreading histogram with different tilt angles α , the minimum spreading corresponds to the tilt angle α_1 . The character height is defined by orthogonal projections of the image features at minimum spread.

The row segmented image for the registration plate area is normalised by resembling in two stages: firstly by rotating the image an angle α according to the definition:

$$\begin{aligned} x' &= x \cos(\alpha_1) - y \sin(\alpha_1) \\ y' &= x \sin(\alpha_1) + y \cos(\alpha_1) \end{aligned}$$

and then a second algorithm is used to adjust the plate size. The transformation is as:

$$x' = kx \text{ and } y' = ky$$

where k is the ratio between the desired plate size and the existing image size in a 20 x 230 pixels plate image.

Characters recognition: The standard size character in the gray level image will be matched to all templates to measure similarity. A cross correlation technique is applied between the sub-image (f) where the character is expected, and the generic template (g), so that the result will be the cross correlation value C_{fg}

$$C_{fg} = \frac{\sum \sum (f - f') (g - g')}{\sqrt{(\sum \sum (f - f')^2) (\sum \sum (g - g')^2)}}$$

where f' , g' are the average gray level of both the generic template and the sub-image. By cross correlation of the sub-image to all generic templates, it will result in a number of cross correlation values. The generic template that gives the maximum cross correlation is the solution.

The generic templates for digits 0 - 9, letters A - Z have a size of 20 x 17 pixels for single characters, while a plate extracted from a car image will be normalised to a 20 x 230 pixel image. Every sub-area will be cross correlated with its corresponding data base, so that the template that has the highest cross correlation will be the matching template.

The Hough Transform

This approach in image transformations was proposed by Hough [16], where the Hough Transform performs a structure of the relationship between pixels in an image. Consider a point (x', y') in a straight line of the equation:

$$y' = mx' + c,$$

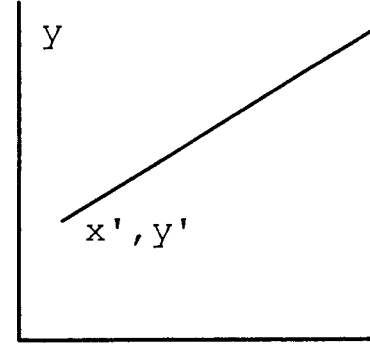


Figure 3: A line in x-y plan

where m is the line slope and c is its intercept. There are an infinite numbers of lines which can pass through this point for different values of m 's and c 's. The variable parameters for the point (x', y') in the image space are in the form:

$$c = -mx' + y'$$

which is an equation for a straight line in parameter space (Figure 3). For another point x'', y'' in the image space, it will be presented as a line in parameter space by the equation $c = -mx'' + y''$. The intersection between the two lines in parameter space at the point m', c' presents an image space line passing by points (x', y') and (x'', y'') , with m' slope and c' intersection parameters.

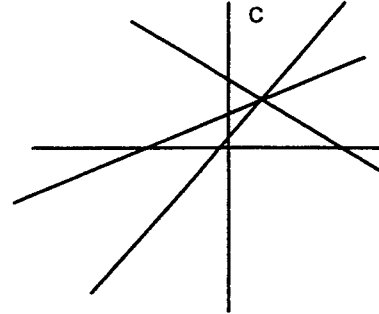


Figure 4: Parameter space and line bundle associated with the solution.

When transferring every pixel of a line in the image space into lines in the parameter space (Figure 4), more lines intersect at the same point presenting a number of points along a line in the image space which is proportional to the length of this line. Computing the number of lines passing by every point of parameter space, by subdividing the parameter space into accumulated cells with appropriate (c_{max}, c_{min}) and (m_{max}, m_{min}) which give the range of slopes and the intercept values. The parameter space is divided into four main quadrants, and then subdivided into smaller cells, where the cell at coordinates (i, j) will have the value $A(i, j)$. After

transformation of the full image if the value $A(i, j)$ is greater than 1 then a solution and the number in this cell is equal to number of points passing by the image space line, and so the location I, j presents the parameters of this line.

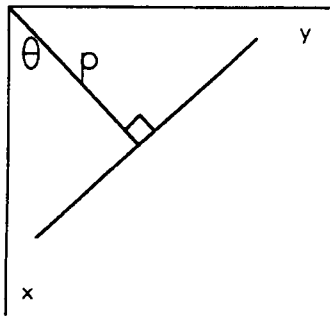


Figure 5: The normal representation of a line.

The normal representation of a line is shown in the Figure 5 where:

$$\rho = x \cos \theta + y \sin \theta$$

also can be transformed in another parameter space ρ, θ where every point in the image space will appear as a sinusoidal curve in the parameter space. When some curves intersect at a point, then this point will be the solution that gives the parameters ρ, θ and the number of intersected curves presents the image line length.

The Hough Transform is a very efficient tool in image identification and image recognition, but it had some difficulties in application:

1. Using the equation $y = mx + c$ does not function for vertical lines where the slope reaches infinity, and the solution point of those lines will be outside the limit of the parameter space. This limits the use of Hough Transform as only to transform the normal presentation of a line ($\rho \cos \theta + y \sin \theta$) can be used.
2. Plotting every point in the image space as a line in the parameter space as point by point plotting, needs a considerable memory and long execution with the use the normal parameters ρ, θ .

The Fast Hough Transform

The algorithms of the Fast Hough Transform (FHT) were proposed by Vuillemin [17] and Guil, Villalaba and Zabata [18] where algorithms use the equation $y = mx - c$ for a straight line detection after solving for problems for the Hough Transform application.

1. **Infinite slope:** The transform is carried out in two stages, firstly with the lines that have slopes between $-1, 1$ by using the equation $y = mx + c$, and then transform the lines that have slopes greater than 1 and less than -1 by using the equation $x = ty + b$ that have slopes (t) between $-1, 1$.

2. **Memory size and calculation time:** Guil, *et al.* [18] used a FHT algorithm to detect the solution point in the parameter space by focalising on them. They divided the parameter space into four quadrants, then every quadrant will be divided again to smaller four quadrants and so forth until it reaches a quadrant of a cell size. To detect a line in the parameter space it is not necessary to perform the calculation for every cell in the parameter space whether the line is passing through this cell or not. The system verifies whether the line crosses a quadrant by measuring the distance between the centre point of the quadrant and the line, by determining if it was greater than the distance between the centre and the quadrant borders. It means that this line is not passing through this quadrant and no calculation is required. But if the distance is less, then the system will go to the smaller sub quadrant and so on until it found the cell that includes the line. Vuillemin [17] used another FHT algorithm similar to the fast Fourier Transform (FFT). The transform is carried out in a number of steps equal to the number of slopes angles required.

PLATE IMAGING METHODOLOGY

This project was conducted to recognise the black and white binary images of registration plate characters after the image processing of a colour image for a car. The procedures which were developed car plate image recognition will be described, together with an evaluation of the primary elements of the imaging system.

Collecting the Data Base

The database in this car registration plate image recognition system is an array of identification for letters A to Z, digits 0 to 9 and the decimal point (used in used in the Australian car registration plate). These identifications were produced by applying the Hough Transform algorithm to character images extracted manually from images of actual car registration plates.

Registration Plate Area Detection

Because of the nature of the car registration plate having dark numbers on a light coloured background, then the contrast of the characters in the plate area is high. Thus, when an image is captured for the front of a car and is stored in the memory, the plate detection algorithm is applied to the plate image to extract the maximum contrast area.

Normalising the Plate

It was expected that the character identification would change with tilting and with varying sizes of the plate. Therefore, it was important to normalise the plate before segmentation and identification. This was achieved by detecting the tilt angle and the size of the segmented plate. By applying the Hough Transform to the lower edge of the plate, the distribution of the number of points at the cells will indicate the tilt. The distribution histogram showed that the horizontal line for the distribution peak at zero slope only, and that tilted lines have two peaks with one around the zero slope (because of the

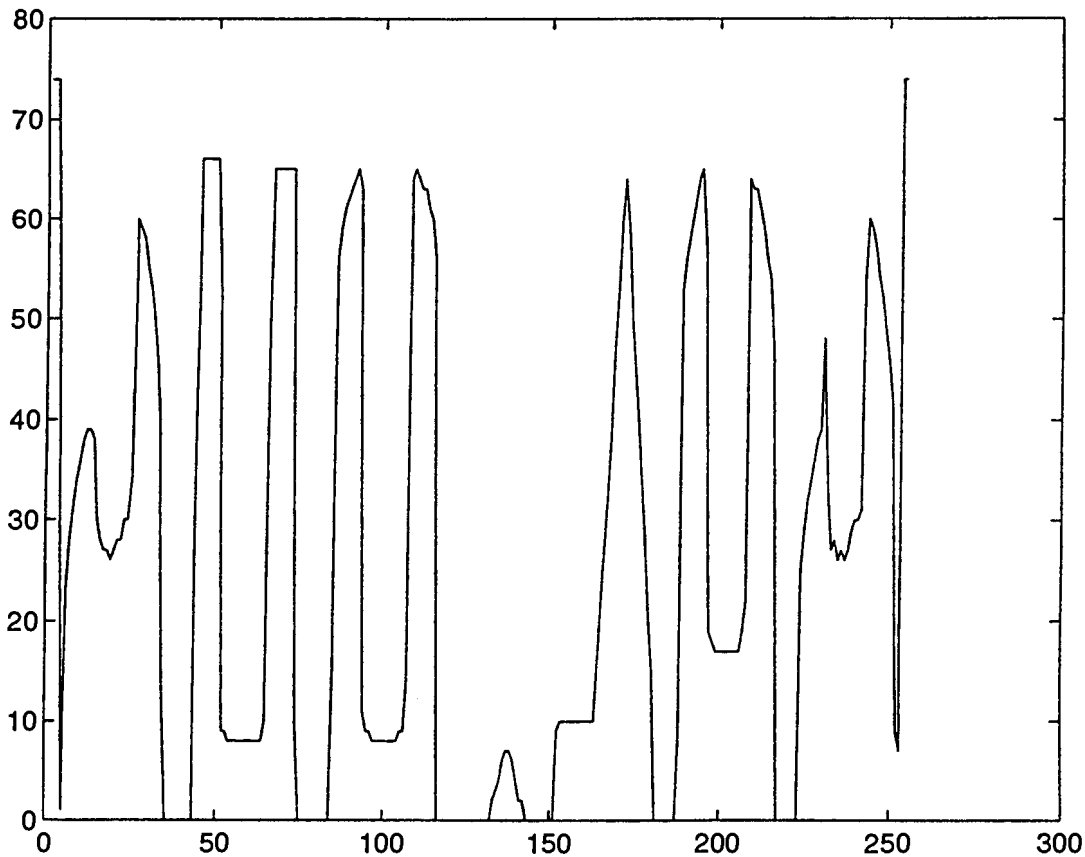


Figure 6: Horizontal colour concentration of characters.

shape of the digital line in the image space) and another peak at a slope (m), so that the system rotates the plate image to a slope ($-m$). The system measured the distance between the top and bottom of the characters and scaled the plate image to the ratio between the normal height to the measured height.

Characters Extraction

The characters extraction process was performed by extracting all characters from the borders, with the boundaries of the horizontal colour concentration (Figure 6) separating the top and the bottom part of the borders. The Figure 6 shows the boundaries between the characters and the side borders and the boundaries between each character within the plate. These boundaries are used by the system to segment the characters. The system follows the boundaries between characters to extract every character.

Edge Detection

Edge detection for the black and white binary image extracted characters was an important process prior to character identification so it was most important to choose an edge detection method which was suitable for the identification technique. The Guil et al. [18] method to solve the infinite slope problem required the splitting of image lines into two groups, with a group for lines of slopes between 1, -1 and the

other group for the remainder of the image lines. The Sobel operator was an ideal technique in this aspect, as it produced these groups by the application of Sobel masks. But there were two problems involved with the use of the Sobel operator:

1. Application of the Sobel operator created a two lines edge with one line in the character side and the other in the background side. This double line required a thinning algorithm to make the edge to be only one line thick. Thinning the edges was achieved by vertically scanning the horizontal edge image produced as a result of the application of the Sobel operator, and by the horizontal scanning of the vertical edge image to combine the double lines into a single line.
2. Filtering the image by a Sobel mask was conducted by a procedure in which every image pixel required nine multiplication and one addition procedure to be filtered, with this process being repeated twice for each direction (vertical and horizontal). A considerable amount of processing time was required for detecting every character edge within the plate, as well as the time required for the thinning algorithm.

Because of the time consumption problem using the Sobel operator another technique was adopted which was more

suitable for binary image edge detection as it required a less number of calculations, so making it faster than by using the Sobel operator. This technique was a very simple edge detection algorithm which scans the binary image horizontally and detects any change from 1 to 0 and 0 to 1, where those changes have produced the vertical edge (Figure 7). Then a similar procedure was used to detect the horizontal edges of the image characters.

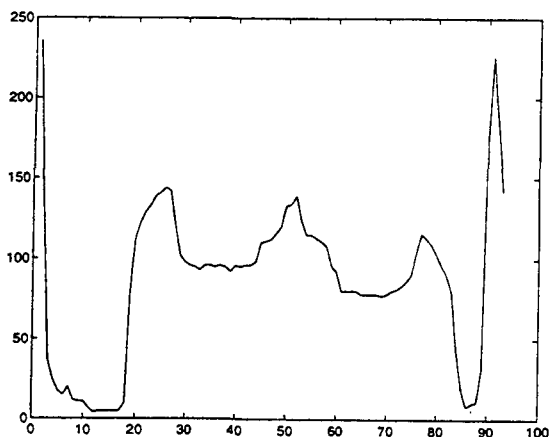


Figure 7: Vertical colour concentration of characters.

Producing the Character Identification

The Hough Transform was used for character identification with the method of Guil *et al.* [18] to solve the problem of infinite slopes. The character identification was performed in two stages with the normal Hough Transform for the horizontal edges and then by rotating the vertical edges 90° by using the equation $x = t \cdot y + b$ (where t is the slope to the x -axis) for the Hough Transform for the vertical edges.

Parameter space structure: The use of a parameter space of the same size as the image space produced an incorrect solution. This problem was created when adjacent points in the image space were transformed into lines in the parameter space, so that the lines produced were very close to each other. As the parameter space cell address was an integer number, then an approximation was required to obtain the integer number for the cell locations. This approximation has made some points of a line to be sharing the same cells with other points of another line, especially around the solution point. As the system was designed to detect the cells that included a number greater than one, then the system should consider the shared points as solution points and so have given false results which are not presentative of the actual number and length of the character edge lines.

The parameter space used in this investigation was designed to have the following shape: the slope (m or t) $\in \{-3, -2, -1, 0, 1, 2, 3\}$ and intercept (c or b) is equal to six times the space image ordinate axis in the horizontal lines process, or six times the image space abscissa axis in the vertical lines process.

Character identification: The application of the Hough Transform algorithm to the horizontal edges of the character image has produced a group of lines in the parameter space. These lines were stored point by point in the accumulated cells of the parameter space, and where an empty cell meant that no lines passed by this point, and that the cells with only one line presenting a part of a transformed line. These conditions of empty cells or single line cells were neglected as they were not presenting any line in the image space. Therefore these were dropped from the identification matrix which has only included the solution points.

The total sum of the contents of the identification matrix produced from the transform of the character image of the horizontal edge, has presented the total length of the horizontal edges (L_h), and the number of active cells of the identification matrix has presented the number of those lines (N_h). A similar procedure was applied to the identification matrix produced from the transform of the character image of the vertical edges, so that this gave L_v and N_v which presented the length and number of vertical edge lines of this character. Any character can be identified by an array (L_h, N_h, L_v, N_v) which is unique to this character.

Matching the Character Identification with the Data Base

The system recognises a character extracted from the registration plate by calculating the error factor (E_{cn}) between the unknown character identification array and the database matrix rows. Let the array of the unknown character be ($L_{hc}, L_{vc}, N_{hc}, N_{vc}$), and the n th row of the database which presents a certain character (n) is ($L_{hdn}, L_{vdn}, N_{hdn}, N_{vdn}$). The error factor between an unknown character and the n th row of the database (E_{cn}) is:

$$E_{cn} = |L_{hdn} - L_{hc}| / L_{hdn} + |L_{vdn} - L_{vc}| / L_{vdn} + |N_{hdn} - N_{hc}| / N_{hdn} + |N_{vdn} - N_{vc}| / N_{vdn}$$

Testing for minimum error for all the database rows, has provided the recognition of characters. If the error was greater than a predetermined threshold then the character was not matched by any of the database characters and not recognised by the system. Otherwise, the minimum error corresponded to the character identification in the database.

PRELIMINARY RESULTS

Preliminary trials were conducted on typical Australian car registration plates (Figure 8) in order to evaluate the effectiveness of the Fast Hough Transform for the identification of characters. A limited number of vehicle registration plates were recorded on video, and digitised images were produced for analyses by the FHT technique.

The Fast Hough Transform method of identification and recognition was applied to these registration plates, with the horizontal and vertical identification parameters shown in the Table 1. Each of the alphabetical and numerical characters has been shown to be unique, but because of the limited nature of investigation then several characters were not surveyed.



Figure 8: Typical Australian car registration plate.

Table 1: Fast Hough Transform identification of registration plate characters.

	lh	nh	lv	nv
0	39	4	173	4
1	16	2	120	2
2	79	7	128	20
3	52	8	110	10
4	43	4	230	25
5	94	12	120	10
6	58	8	156	15
7	49	3	113	17
8	63	10	204	15
9	61	9	142	12
A	40	4	271	45
B	74	8	243	20
C	61	8	117	9
D	44	6	225	18
E	102	8	124	7
F	93	7	117	5
G	85	10	180	15
H	51	5	248	13
I	34	4	130	9
J	36	5	128	5
K	31	3	318	38
L	51	4	117	4
M	29	3	465	55
N	24	2	434	54
O	64	8	217	15
P	64	7	161	9
Q	*	*	*	*
R	60	6	242	22
S	70	9	129	15
T	46	3	116	4
U	37	4	263	19
V	*	*	*	*
W	37	5	186	21
X	24	3	368	59
Y	*	*	*	*
Z	91	4	136	21

However, these results can be improved with regard to the relative similarity of some identifications in Table 1. Thus it was necessary to create a more distinctive identification. The transformed character image in the parameter space (Figure 9) will produce solution points in any quadrant of the parameter space. Therefore it is possible to separate the points of every quadrant to extend the identification array to become in the form:

[L_{ha} , L_{hs} , L_{ht} , L_{hc} , N_{ha} , N_{hs} , N_{ht} , N_{hc} , L_{va} , L_{vs} , L_{vt} , L_{vc} , N_{va} , N_{vs} , N_{vt} , N_{vc}]

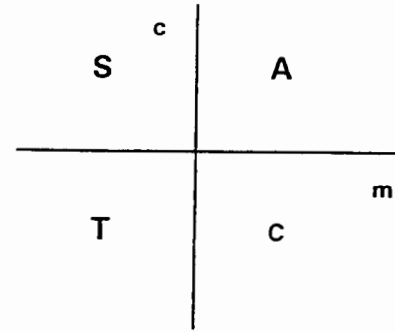


Figure 9: The quadrants of the parameter space.

The database for the extended identification shows that there is no solution for the vertical transform in the C-quadrant and in the horizontal transform in the T-quadrant. Therefore it is possible to reduce the number of elements for the extended identification to become:

[L_{ha} , L_{hs} , L_{hc} , N_{ha} , N_{hs} , N_{hc} , L_{va} , L_{vs} , L_{vt} , N_{va} , N_{vs} , N_{vt}]

The analysis of the transform has shown that the reason for the disappearance of the solution points of the vertical transform in the C-quadrant is due to the lines in the image space which have positive slope to the x-axis (between 90°, 135° to the horizontal) and situated in the positive part of the image space will never have chance to intersect with the negative part of the y axis. Also the solution points of the horizontal transform will not appear in the T-quadrant due to the lines in the image space that have negative slope to the y-axis (between 0°, - 45° to the horizontal) and situated in the positive part of the image space will never have chance to intersect with the negative part of the y axis.

The development of the extended character identification profile (Table 2) has provided a more substantial identification configuration for character recognition. The research will continue to further improve the rate of successful recognition and the recognition time for the identification of registration plate characters.

Table 2: Extended character identification profile.

	lha	lhs	lhc	nha	nhs	nhc	lva	lvs	lvt	nva	nvs	nvt
0	43	0	4	5	0	1	198	176	152	10	43	38
1	16	0	0	2	0	0	120	0	0	2	0	0
2	81	9	5	8	2	1	107	97	0	17	19	0
3	59	4	5	10	1	1	121	54	12	13	12	3
4	43	0	0	4	0	0	144	140	50	13	26	12
5	105	9	0	15	2	0	116	23	47	10	5	11
6	55	7	0	8	1	0	121	67	61	9	15	14
7	49	0	0	3	0	0	122	45	4	20	9	1
8	79	8	4	14	2	1	187	97	69	13	23	16
9	59	10	4	9	2	1	156	80	64	17	18	15
.	4	8	0	1	2	0	0	8	0	0	2	0
A	48	0	0	6	0	0	214	129	92	36	28	20
B	82	5	4	10	1	1	193	112	70	11	26	16
C	69	4	8	10	1	2	105	21	27	7	5	6
D	47	0	25	7	0	6	249	166	110	25	40	27
E	106	8	0	9	2	0	119	35	8	6	8	2
F	93	0	0	7	0	0	117	16	8	5	4	2
G	82	5	10	10	1	2	150	25	66	10	6	14
H	51	0	0	5	0	0	235	90	72	11	22	17
I	38	0	0	5	0	0	140	51	4	12	11	1
J	44	0	0	7	0	0	123	47	9	4	11	2
K	35	4	0	4	1	0	269	140	88	31	30	20
L	51	0	0	4	0	0	121	0	12	5	0	3
M	41	0	0	6	0	0	353	219	149	39	45	31
N	28	0	4	3	0	1	319	195	118	35	41	26
O	62	5	5	8	1	1	214	133	108	16	32	26
P	58	4	6	6	1	1	170	62	12	12	14	3
Q	*	*	*	*	*	*	*	*	*	*	*	*
R	60	0	0	6	0	0	228	101	90	21	24	21
S	90	8	8	14	2	2	132	25	61	17	6	14
T	50	0	0	4	0	0	120	12	4	5	3	1
U	41	0	0	5	0	0	222	142	118	12	33	28
V	*	*	*	*	*	*	*	*	*	*	*	*
W	37	4	4	5	1	1	186	74	46	22	17	11
X	32	4	0	5	1	0	296	194	89	48	39	21
Y	*	*	*	*	*	*	*	*	*	*	*	*
Z	99	0	0	6	0	0	86	144	0	13	30	0

CONCLUSION

This investigation has proposed an alternative method for the recognition of characters on car registration plates for the identification of vehicles. The Fast Hough Transform approach has been examined as a technique for optical character recognition. The paper has developed the Hough Transform as a methodology for accurate and rapid identification of characters on Australian vehicle registration plates. Although the technique is still in the development phase, sufficient evidence has been presented which indicates the potential for this proposed approach to character recognition.

The study has demonstrated that both alphabetical and numerical characters can be shown to have unique profiles from digital processing. The Fast Hough Transform approach to optical character recognition is an unfamiliar method which

has merit in its application. Further development is needed to reduce processing time and further increase accuracy of identification, but the fundamental premise of the Fast Hough Transform as a valid optical character recognition technique has been established.

REFERENCES

- [1] R. Lotufo, A.D. Morgan, and A.S. Johnson, "Automatic number-plate recognition" in *IEEE Colloquium Image Analysis for Transport Applications* (Digest No 035), 1990, pp. 671-676.
- [2] M.M. Fahmy, "Automatic number-plate recognition: neural network approach" in *Vehicle Navigation And Information Systems Conference Proceeding*, 1994, pp. 99-101.
- [3] E.R. Lee, P.K. Kim, and H.J. Kim, "Automatic recognition of a car license plate using colour image

- processing", in *Proceedings of the International Conference on Image Processing*, 1994, vol. 2, pp. 301- 305.
- [4] P. Comelli, M.N. Ferragina, Granieri, and F. Stabil, "Optical recognition of motor vehicle license plate", in *IEEE Transaction on Vehicular Technology*, 1995, vol. 44, pp. 700-709.
 - [5] R.C. Gonzalez, and P. Wintz, *Digital Image Processing (2nd edition)*. New York: Addison-Wesley Publishing Company, 1987.
 - [6] R.M. Haralick, and L.G. Shapiro, *Computer and Robot Vision*. Addison-Wesley Publishing Company, 1992.
 - [7] B.A. Harrison and D.L.B. Jupp, *Introduction to Image Processing*. Australia: CSIRO, 1990.
 - [8] I.E. Sobel, *Camera Model and Machine Perception*, Ph. D. Thesis, Electrical Engineering Department, Stanford University, Stanford, CA., 1970.
 - [9] W. Frei and C.C. Chen, "Fast boundary detection: A generalisation and new algorithm", *IEEE Transactions on Computers*, vol. C-26, pp. 556-566, 1977.
 - [10] R. Jain, "Dynamic scene analysis using pixel-based processing" *Computer*, vol. 14, pp. 12-18, 1981.
 - [11] R. Jain, "Segmentation of frame sequences obtained by moving observer", *Report gmr-4247, General Motors Research Laboratories*, Warren, Mich., 1983.
 - [12] S.A. Rajala, A.N. Riddle and W.E. Snyder, "Application of the one dimensional Fourier Transform for tracking moving object in noisy environments", *Comput. Vis. Graph. Image Proc*, vol. 21, pp. 280-293, 1983.
 - [13] J.T. Tou and R.C. Gonzalea, *Pattern Recognition*. Reading, Mass.: Addison-Wesley, 1974.
 - [14] M. Horowitz, "Efficient use of a picture correlator", *J.Opt. Soc. Am*, vol. 47, pp. 327, 1957.
 - [15] F. Rosenblatt, *Principles of Neurodynamics*. Washington: Spartan Books, 1962.
 - [16] P.V.C. Hough, "A method and means for recognizing complex pattern", *US. Patent No. 3,069,654*, 1962.
 - [17] J.E. Vuillemin, "Fast linear Hough Transform", in *Proceedings of the International Conference on Application Specific Frequency*, 1994, pp. 1-9.
 - [18] N. Guil, J. Villaba, and E.L. Zabata, "A Fast Hough Transform for segment detection" in *IEEE Transaction on Image Processing*, 1995, vol. 4, iss 11, pp. 1541-1548.

Appendix B

The Project Algorithm Subroutines

% Subroutine 1

**% This program to get a plate from a car image stored in the memory by
% its number this program also to normalize the plate if required**

```
function [y,m] = getpl(x)
[l,m]=locplate(x); % Sub (2)
a=angle(l);        % Sub (3)
x1=int2str(x);
q=['plate',setstr(x1),'.bmp'];
[x,map]=bmpread (q);
if a~=0
    r=imrotate(x,a);
    l=alocatepl (r,map); % Sub (4)
end
y=l;
m=map;
```

% Subroutine 2

% This program is to locate the plate area from car image
% the plate is stored in memory the input is the plate
% number in two digits, this use the remap method

```
function [y,map] = loctplate(x)
x1=int2str(x);
l=['plate',setstr(x1),'.bmp'];
[x,map]=bmpread(l);
subplot(2,1,1);
imshow(x,map)
[R,C]=size(x);
a=zeros(R,C);
m=remap(map);    % Sub (5)
p=find(sum(m')<3);
s=size (p);
for d=1:s(2)
    f=find (x==p(d));
    a(f)=1;
end
subplot(2,1,2);
b=sum(a);
b1=b-mean(b);
m=b1.*(b1>0);
f=wid(m);    %Sub (6)
l=min(find(f==1));
h=max(find(f==1));
k=a(1:R,l:h);
subplot(2,1,2);
a1=k;
b=sum(a1');
b1=b-mean(b);
m=b1.*(b1>0);
f=wid(m);    %Sub (6)
t=find(f>0);
z=contin(t);    % Sub (9)
k=x(z(1):z(2),l:h);
[r,c]=size(k);
```

```

if c/r<2.5
    k=remap1(x,map);    % Sub (7)
elseif c/r>3.25
    k=remap1(x,map);
end
[r,c]=size(k);
if c/r<2.5
    k=remap2(x,map);
elseif c/r>3.25
    k=remap2(x,map);    % Sub (8)
end
subplot(2,1,2);
imshow (k,map)
y=k;
map=map;

```

% Subroutine 3

**% This program is to calculate the slope angle of a binary image
% of a registration plate.**

```
function y=angle (x)
a=x>50;
b=hedge(a); % Sub (18)
[Y,X]=size(b);
m=zeros(fix(1.5*Y),20);
for x = 1 : X
    for y = 1 : Y
        if b(y,x) == 1
            for M = 1 :20
                c = y - (M-10)*x/50;
                if c<Y
                    if c>(1-Y/2)
                        c=fix ( c +Y/2 );
                        m ( c ,M ) = m ( c , M ) + 1;
                    end
                end
            end
        end
    end
end
z=m>70;
q=sum(z.*m);
w=find(q==max(q));
if w==10
    an=0;
elseif w>10
    n=w-10;
    an=180*atan(n/50)/pi;
else
    n=10-w;
    an=-(180*atan(n/50)/pi);
end
y=an;
```


%Subroutine 4

% This program is to locate the plate area from car image
% the plate the input is the plate image in indexed color and map

```
function y = allocatepl(x,map)
subplot(2,1,1);
imshow(x,map)
[R,C]=size(x);
a=zeros(R,C);
m=remap(map);
p=find(sum(m')<3);
s=size (p);
for d=1:s(2)
    f=find (x==p(d));
    a(f)=1;
end
subplot(2,1,2);
imshow(a)
b=sum(a);
b1=b-mean(b);
m=b1.*(b1>0);
f=wid(m);
l=min(find(f==1));
h=max(find(f==1));
k=a(1:R,l:h);
subplot(2,1,2);
a1=k;
b=sum(a1');
b1=b-mean(b);
m=b1.*(b1>0);
f=wid(m);
t=find(f>0);
z=tagarob(t);
k=x(z(1):z(2),l:h);
M=brighten(map,.1);
[r,c]=size(k)
```

```

if c/r<2.5
    k=remap1(x,M);
elseif c/r>3.25
    k=remap1(x,M);
end
[r,c]=size(k)
if c/r<2.5
    k=remap2(x,map);
elseif c/r>3.25
    k=remap2(x,map);
end
subplot(2,1,2);
imshow (k,map)
y=k;

```

% Subroutine 5

**% This program is to adjust the colour map to detect yellow color
% areas of the image**

```
function y = remap(x)
[R,C]=size(x);
for r=1:R
    if x(r,1)<.35
        x(r,1:3)= ones(1,3);
    end
    if x(r,2)<.4
        x(r,1:3)=ones(1,3);
    end
    if x(r,2)>.99
        x(r,1:3)=ones(1,3);
    end
    if x(r,3)>.35
        x(r,1:3)=ones(1,3);
    end
end
end
y=x;
```

Subroutine 6

%This program to detect the position of positive pulses in a histogram

```
function y = wid (x)
s=size (x);
a=zeros(s);
for c =5:s(2)-5
    if sum(x(c:c+4))>0
        a(c:c+4)=ones(1,5);
    end
end
y=a;
```

% Subroutine 7

**% This program is to adjust the colour map to detect yellow color
% areas of the image in the light mode , and locate the plate and return
% the plate location**

```
function y = remap1(L,m1)
[q,w]=size(L);
a=zeros(q,w);
m=brighten(m1,.20);
[R,C]=size(m);
for r=1:R
    if m(r,1)<.45
        m(r,1:3)=ones(1,3);
    end
    if m(r,2)<.455
        m(r,1:3)=ones(1,3);
    end
    if m(r,2)>.99
        m(r,1:3)=ones(1,3);
    end
    if m(r,3)>.45
        m(r,1:3)=ones(1,3);
    end
end
p=find(sum(m')<3);
s=size (p);
for d=1:s(2)
    f=find (L== p(d));
    a(f)=1;
end
subplot(2,1,2);
b=sum(a);
b1=b-mean(b);
m=b1.*(b1>0);
f=wid(m);    Sub (6)
l=min(find(f==1));
h=max(find(f==1));
k=a(1:q,l:h);
subplot(2,1,2);
a1=k;
b=sum(a1');
b1=b-mean(b);
```

```
m=b1.*(b1>0);  
f=wid(m);    Sub (6)  
t=find(f>0);  
z=contin(t);    % Sub (9)  
k=L(z(1):z(2),l:h);  
y=k;
```

% Subroutine 8

**% This program is to adjust the colour map to detect yellow color
% areas of the image in the dark mode , and locate the plate and return
% the plate location**

```
function y = remap2(L,m1)
[q,w]=size(L);
a=zeros(q,w);
m=brighten(m1,-.20);
[R,C]=size(m);
for r=1:R
    if m(r,1)<.45
        m(r,1:3)=ones(1,3);
    end
    if m(r,2)<.455
        m(r,1:3)=ones(1,3);
    end
    if m(r,2)>.99
        m(r,1:3)=ones(1,3);
    end
    if m(r,3)>.4
        m(r,1:3)=ones(1,3);
    end
end
p=find(sum(m')<3);
s=size (p);
for d=1:s(2)
    f=find (L==p(d));
    a(f)=1;
end
subplot(2,1,2);
b=sum(a);
b1=b-mean(b);
m=b1.*(b1>0);
f=wid(m);    Sub (6)
l=min(find(f==1));
h=max(find(f==1));
```

```
k=a(1:q,1:h);  
subplot(2,1,2);  
a1=k;  
b=sum(a1');  
b1=b-mean(b);  
m=b1.*(b1>0);  
f=wid(m);  
t=find(f>0);  
z=contin(t);    Sub (9)  
k=L(z(1):z(2),1:h);  
y=k;
```


% Subroutine 9

% This program is to calculate the width of continuity in a distribution

```
function y = contin(x)
[r,c]=size(x);
if r==0
    Y=[];
else
    b=1;
    e(b)=x(c);
    s(b)=x(1);
    for a =2:c-1
        if x(a)~=x(a-1)+1
            e(b)=x(a-1);
            b=b+1;
            s(b)=x(a);
        end
    end
    k=size(s);
    l=size(e);
    if k(2)>l(2)
        e(b)=x(c);
    end
    w=e-s;
    n=find(w==max(w));
    Y=[s(n),e(n)];
end
y=Y;
```

% Subroutine 10

% This program to recognize an extracted couler plate

```
function y = platerecog (p,m)
g=ind2gray(p,m);
[R,C]=size(g);
S=sum(sum(g));
u=S/(1.45*R*C);
bw=g<u;
bw(1:2,1:C)=zeros(2,C);
bw(R-1:R,1:C)=zeros(2,C);
bw(1:R,1:3)=zeros(R,3);
bw(1:R,C-2:C)=zeros(R,3);
b=edfilter(bw);    Sub (12)
s=sum(b');
a=ava(s);
m=mean(a);
a=a-m;
z=a>0;
f=find (z==1);
[r,c]=size (f);
if f(2)-f(1)>1
    f(1)=f(2);
elseif f(c)-f(c-1)>1
    (c)=f(c-1);
end
T=f(1);B=f(c);
[R,C]=size(b);
b1=b(T:B,1:C);
s=sum(b1);
a=ava(s);
m=mean(a);
z=(a-.6*m)>0;
f=find (z==1);
[r,c]=size (f);
```

```

if f(2)-f(1)>1
    f(1)=f(2);
elseif f(c)-f(c-1)>1
    f(c)=f(c-1);
end
L=f(1);R=f(c);
b2=bw(T-1:B+1,L-1:R+1);
l=plrecog(b2);    Sub (13)
subplot(1,1,1)
imshow(b2)
y=l;

```

% Subroutine 12

**% This program is to filter the plate from the thin lines around a binary %
plate image where the character are in white and background in black**

```
function y = edfilter(a)
A=size(a);
n=a;
s2=sum(a');
f2=find(s2>.65*A(2));
if ~isempty(f2)
    F=size(f2);
    for p=1:F(2)
        n(f2(p),1:A(2))=zeros(1,A(2));
    end
end
m3=zeros(1,4);
m4=zeros(4,1);
for x=1:3:A(2)-3
    for y=1:3:A(1)-3
        b=n(y:y+3,x:x+3);
        for t=1:4
            s=sum(b(t,1:4));
            if s==1
                n(y+t-1,x:x+3)=m3;
            elseif s==2
                n(y+t-1,x:x+3)=m3;
            end
            s=sum(b(1:4,t));
            if s==1
                n(y:y+3,x+t-1)=m4;
            elseif s==2
                n(y:y+3,x+t-1)=m4;
            end
        end
    end
end
y=n;
```

% Subroutine 13

**% This program to separate characters within a binary plate image and
% recognize them, the characters are in white and a black background**

```
function y = plrecog (x)
[n,p]=size (x);
f=sum(x);
m=min(f);
if m==0
    m=m+1;
end
s=0;
while s<20
    s=sum(f<=m);
    m=m+1;
end
m=m-1;
g=f<=m;
e=1;
c=1;
s=1;
while s~=0
    if g(c)==0
        if g(c+1)==1
            u(e)=c+1;
            c1=u(e);
            m=e;
            while m==e
                if g(c1)==1
                    if g(c1+1)==0
                        d(e)=c1;
                        e=e+1;
                        m=0;
                        c=c1;
                        if c==p-1
                            m=0;
                        end
                    end
                end
                c1=c1+1;
                if c1==p-1
                    m=0;
                end
            end
        end
    end
    s=1;
end
```

```

        end
    end
end
c=c+1;
if c==p-2
    s=0;
end
end
i=size(u);
j=size(d);
if i(2) > j(2)
    u=u(1,1:j(2));
end
s=[u;d];
[N,P]=size (s);
L(1)=2;
C=1;
for m= 1 : P
    if s(2,m)-s(1,m)>=2
        R(C)=s(1,m)-1;
        C=C+1;
        L(C)=s(2,m)+1;
    end
end
R(C)=p;
[N,P]=size (R);
C=1;
for m= 1 : P
    if R(1,m)-L(1,m)>p/50
        r(C)=fix(R(1,m));
        l(C)=fix(L(1,m));
        C=C+1;
    end
end
[N,P]=size (l);
for z = 1 : P
    a=l(z);
    b=r(z);
    q=x(1:n,a:b);
    q= chskl(q);    Sub (14)
    w(z)=recog(q);  Sub (15)
end
y=w;

```

% Subroutine 14

**% This program is to extract the character and resize it to a standard size
% and to fit a standard border around it; the character is in bit map
% binary form .**

```
function y = chskl(x)
a=x=1;
v=sum(a');
t=min(find(v>=1));
b=max(find(v>=1));
h=sum(a);
l=min(find(h>=1));
r=max(find(h>=1));
nb=a(t:b,l:r);
y=border(nb);      Sub (16)
```

% Subroutine 15

**% This program to recognize a character by producing its identification %
array and comparing it with the data base,**

```
function y = recogn ( a )
a= idarray (a)      Sub (17);
fid=fopen('toto.dat','a+');
d=fread(fid,[37,17],'float');
e=zeros(1,37);
for dat = 1:37
    id=d(dat,2:17);
    e(dat)=sum((abs(a- id))./(sqrt(abs(id.^2-a.^2))+1));
end
s=min(e);
r=find(e==s);
if r > 11
    char=r+53;
elseif r ==11
    char=46;
else
    char=r+47;
end
y=setstr(char);
```


% Subroutine 16

**% This program is to resize the separated character and put a standard
% border around it.**

```
function y = border(x)
[r,c]=size (x);
if r>20
    x=imresize(x,54/r);
    [R,C]=size(x);
    z=[zeros(R,3),x,zeros(R,3)];
    w=[zeros(C+6,3),z',zeros(C+6,3)];
else
    x=imresize(x,5/r);
    [R,C]=size(x);
    z=[zeros(R,25),x,zeros(R,25)];
    w=[zeros(C+50,3),z',zeros(C+50,3)];
end
y=w';
```

% Subroutine 17

% This is to produce an identification array for a binary character image

```
function m = idarray (a)
%parameter space in the x direction
h=hedge (a)    Sub (18);
[Y,X] = size(a);
matrixx=zeros(6*Y,7);
for x = 1 : X
    for y = 1 : Y
        if h(y,x) == 1
            for M = 1 : 7
                c = y - (M-4)*x/3 ;
                if c<Y
                    if c>(1-Y)
                        c=fix(3 * ( c + Y ));
                        matrixx ( c ,M ) = matrixx ( c , M ) + 1;
                    end
                end
            end
        end
    end
end
end
z=matrixx;
p = matrixx >=4;
lxa= sum ( sum ( matrixx(1:3*Y,4:7). *p(1:3*Y,4:7)));
lxt= sum ( sum ( matrixx(3*Y+1:6*Y,1:3). *p(3*Y+1:6*Y,1:3)));
lxc= sum ( sum ( matrixx(3*Y+1:6*Y,4:7). *p(3*Y+1:6*Y,4:7)));
nxa= sum ( sum (p(1:3*Y,4:7)));
nxt= sum ( sum (p(3*Y+1:6*Y,1:3)));
nxc= sum ( sum (p(3*Y+1:6*Y,4:7)));
x=[lxa,lxt,lxc,nxa,nxt,nxc];
```

```

%parameter space in the y direction
v= vedge (a);
[Y,X]=size(a)    Sub (19);
matrixy = zeros ( 6*Y,7 );
for x = 1 : X
    for y = 1 : Y
        if v(y,x) == 1
            for T = 1 : 7
                c = (T-4)*y/3 - x;
                if c < Y
                    if c >=(1-Y)
                        c=fix(3 * ( c + Y ));
                        matrixy(c,T)=matrixy(c,T)+1;
                    end
                end
            end
        end
    end
end
end
p = matrixy >=4;
lya= sum ( sum ( matrixy(1:3*Y,4:7).*p(1:3*Y,4:7)));
lys= sum ( sum ( matrixy(1:3*Y,1:3).*p(1:3*Y,1:3)));
lyc= sum ( sum ( matrixy(3*Y+1:6*Y,4:7).*p(3*Y+1:6*Y,4:7)));
nya= sum ( sum (p(1:3*Y,4:7)));
nys= sum ( sum (p(1:3*Y,1:3)));
nyc= sum ( sum (p(3*Y+1:6*Y,4:7)));
y=[lya,lys,lyc,nya,nys,nyc];
m=[x y];

```

% Subroutine 18

% This program is to detect the horizontal edges in a binary image.

```
function y = hedge (a)
h=ones(32,32);
for c = 1: 32
    for r = 1 : 32
        if a (r,c) ~= a ( r+1,c )
            h ( r,c ) = a ( r , c );
            h ( r+1,c ) = a ( r+1,c );
        end
    end
end
end
```

% Subroutine 19

% This program is to detect the vertical edges of a binary image.

```
function y = vedge (a)
[R,C]=size(a);
v=zeros(R,C);
for c = 1: C-1
    for r = 1 : R
        if a( r,c ) ~= a( r,c+1 )
            v ( r,c ) = a ( r , c );
            v ( r,c+1 ) = a ( r,c+1);
        end
    end
end
y=v;
```